EXPERT SYSTEM FOR GENERALIZED SCHEDULING AND TOOL MANAGEMENT IN FMS ENVIRONMENT

by

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INDUSTRIAL AND MANAGEMENT ENGINEERING PROGRAMME
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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CERTIFICATE

This to certify that this work on " EXPERT SYSTEM FOR GENERALIZED SCHEDULING AND TOOL MANAGEMENT IN FMS", by DIVAKER, has been carried out under my supervision and that this has not been submitted elsewhere for a degree.

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Divaker

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ABSTRACT

In the present work, an attempt has been made to develop an expert system for generalized scheduling and tool management in FMS environment. The developed system contains four loading heuristics for scheduling under generalized conditions. Three of these are 1) Shortest Processing Time (SPT), 2) Most Work Remaining (MWKR) and 3) Most Operations Remaining (MOPR). A weightage scheme has been proposed for giving due importance to various parameters of FMS e.g. pallets and fixtures. The fourth heuristic which draws upon the proposed weightage scheme has been devised and implemented. The algorithm for generalized scheduling in FMS has been illustrated with the help of three illustrative examples. A performance comparison of the four heuristics, in terms of flow time, waiting time, makespan time and the utilization of the various resources like machines, pallets and fixtures, for the three illustrative problems has been presented. An algorithm for tool management in FMS has also been proposed and implemented.

The developed system takes into consideration an FMS environment which constitutes of machines, pallets, fixtures, material handling equipments, tools and jobs to be scheduled. The system can also take care of varying batch sizes of jobs which are to be scheduled for operations. The various operations of a job can have linear precedence constraints and/or non-linear (generalized) precedence constraints among them.

The system has been implemented in Prolog. It is supported by a graphical interface which can display the generated schedules in the form of Gantt charts. The percentage utilization of resources can be displayed on a real time scale. The entire system is menu driven and user friendly.

CHAPTER I

INTRODUCTION

In recent years, the manufacturing industry has undergone dramatic changes due to the diversification of market needs, rapid growth of competition in the global market and sophistication of products. Sound domestic markets with few competitors, stabilized products and predictable economic growth are vanishing very fast. The manufacturers have to continuously evolve manufacturing technologies to remain in the market and to maintain the competitive edge.

Manufacturing industries, in general, require to produce in the most cost effective manner, a large variety of complex components with a small batch size. Further, it is required to reduce costs by the elimination of non value-added activities in supply, production and distribution. In order to accomplish these characteristic changes in production philosophy and to achieve improvements of productivity and quality, together with reduction in lead time and work-in-process, the introduction of flexible manufacturing system has become the nucleus in modern manufacturing industry.

1.1 HISTORY OF FMS

In a traditional batch manufacturing environment, the work in process levels are high and machine utilization is low. A high proportion of time is spent, by the jobs, waiting for something

to happen to them. This waiting time comprises of machine set-up time, waiting time for movement between machines or waiting for other jobs on the machine to be completed. An army of expediters or progress chasers is frequently required in batch production so as to keep jobs flowing through the manufacturing facilities.

The, aforesaid, inherent limitation of traditional batch manufacturing made it desirable to have some means of automatically routing jobs through the manufacturing system from one machine to the next and some way of reducing the machine set-up time of jobs to the extent possible. About 20 years ago a number of independent groups seem to have observed that both of these requirements could be met with the aid of computers and numerical control techniques and this led to the development of the basic concept of flexible manufacturing system [1].

Although the initial implementation of the concept was slow but in the recent past take off has been very fast. Some of the important FMS installations which are operating in industry around the world are at Fanuc, ASEA, Citreon, Hitachi, IPA, KTM, Mori Seiki, Okuma Machinery Works, Reishaw, Sandrik, SMT Machines Tools and Volvo.

1.2 WHAT IS AN FMS ?

The FMS concept was originally developed within the context of machining piece parts. Several definitions for FMS have been proposed. One such definition which is due to Kearney and Trecker [1] is as follows:

"FMS combines the existing technology of NC manufacturing,

automated material handling, and computer hardware and software to create an integrated system for the automatic random processing of palletized parts across various wok stations in the system."

In other words an FMS is a complex network of process control computers, numerically controlled machines, automated material handling and storage systems, and other processes. Fundamentally, it is but one instance of a generalized operations system. It is characterized by the execution of concurrent production processes with synchronous or asynchronous control requirements, deterministic or non-deterministic process operation, and is constrained by limited, usually expensive, resources. Capabilities of the system include data and material acquisition, transformational processes, information and product output and process accounting [2]. The concept of integrated information and material flow in an automatic manufacturing system is shown in Fig 1.1.

1.3 INGREDIENTS OF FMS

A generic FMS consists of the following components:

i) A set of machines or work stations, having some degree of flexibility and significantly low set-up time or change over time between successive jobs.

ii) An automated and flexible material handling system that permits jobs to move between any pair of machines so that any job routing can be followed.

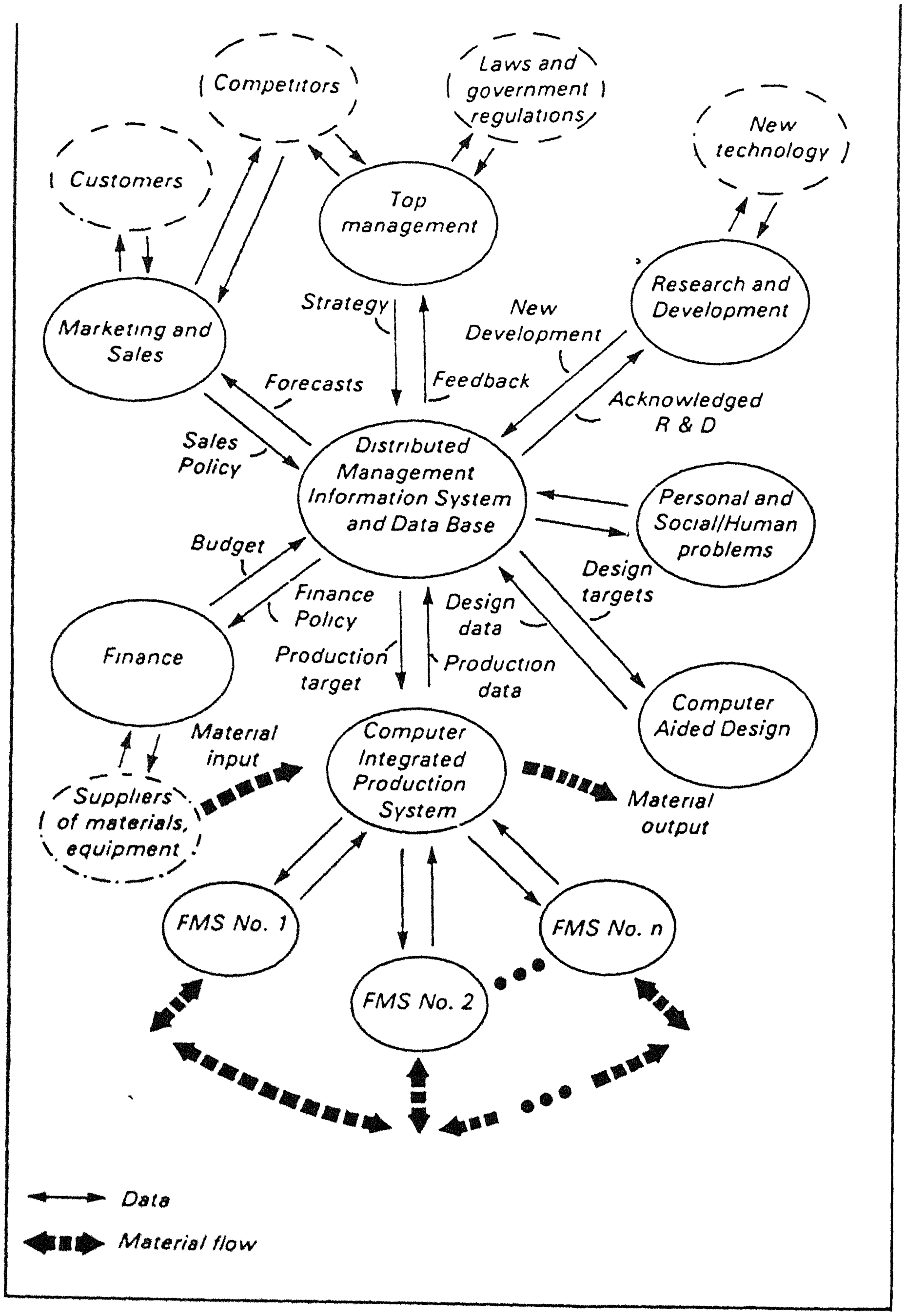


FIG 1.1 THE CONCEPT OF THE INTEGRATED INFORMATION AND MATERIAL FLOW IN FMS

iii) A network of computers and microprocessors which performs some or all of the working tasks :

- Directs the routing of jobs through the system.
- Keeps track of the status of all the jobs in progress.
- Passes the instructions for the processing of each operation to each station and ensures that the right tools are available for the machining of the job.
- Warning signals depicting production problems requiring attention.

iv) Storage, locally at the workstations, and/or centrally at the system level.

v) Jobs to processed by the system which are mounted on pallets and/or fixtures which are limited in number.

vi) Tools, that are either kept at each machine or delivered to each machines from a central tool store by a special delivery system.

1.4 ECONOMIC JUSTIFICATION OF FMS

The basic reasons for designing and implementing flexible manufacturing system are [3] :

a. Greater productivity i.e. a greater output and a lower unit cost.

b. 45-85% smaller floor space requirements.

c. Uniform and consistent quality.

d. Increased overall reliability of production as the machines are equipped with sensory feedback system.

e. Parts can be randomly produced in batches of one.

f. Reduction in lead time by 50-75%.

g. High machine utilization.

1.5 CRUCIAL DECISION ON THE INGREDIENTS OF FMS

1.5.1 Machine Tools

Computer controlled machines are the building blocks of FMS. The selection of the particular machine that comprises an FMS depends on the processing requirements to be accomplished by the system. The design of the parts handling system is also influenced by the processing needs.

Following are some of the factors that define the processing requirement [4] :

(i) Part Size : The size of the work parts to be processed determines the size and construction of the machine.

(ii) Part Shape : The work part shape is broadly classified into round and prismatic.

(iii) Part Variety : For limited part variety the machine tools are more specialized and the FMS is designed as a special system. In case of wide variety of parts the standard machine tools which are more versatile are selected.

(iv) Product Life Cycle : If the product life cycle is relatively long, the FMS can include more specialized and less flexible machine tools.

(v) Definition of future parts : The knowledge about the parts which are to be processed in future greatly influences the versatility and flexibility of FMS machine tools.

The choice of correct machine tools is imperative in order to extract maximum benefits out of an FMS installation. The CNC

machine tools are capital intensive and, therefore, the quantity as well as the type of machine tools to be installed must be decided according to the factors mentioned above. More specialized manufacturing systems may yield low machine utilization due to a change in product variety or reduction in demands. **Whereas greater flexibility and versatility of machine tools poses routing and scheduling problems in order to maintain the machine utilization at the maximum.**

1.5.2 MATERIAL HANDLING SYSTEMS

The material handling system in an FMS must be designed to serve two functions:

a) To move workparts between machines.

b) To orient and locate workparts for processing at machines.

These are often referred to as the primary handling system and the secondary handling system respectively.

The perquisites of the primary handling system are :

(i) It must be compatible with computer control.

(ii) It must provide random, independent movement of palletized workparts between machine tools.

(iii) It must permit temporary storage or banking of workparts.

(iv) It should allow to access the machine-tool for maintenance, tool changing and so on.

(v) It must interface with secondary work handling system.

The requirements placed on the secondary material handling system are :

(i) It must be compatible with computer control.

(ii) It must interface with primary handling system.

(iii) It must permit temporary storage of work parts.

(iv) It must provide space for parts orientation and location at each work station for processing.

(v) It should allow access to the machine tool for maintenance, tool changing and so on.

1.5.2.1 FMS LAYOUTS

The transfer time and transfer paths between the machines in an FMS are highly dependent on the layout of FMS.

The layouts for FMS can be classified into:

(i) Random Layout(Fig 1.2 a) :- Here a number of machines are laid out in a rectangular shop. The disadvantage of this layout is that with more than three machines, transfer paths are complicated and are likely to be larger than necessary.

(ii) Functional Layout(Fig 1.2 b) :- Here machines are arranged according to the functions, such as turning, milling, drilling, etc., so that the work pieces flow through the shop from one end to the other.

(iii) Modular Layout(Fig 1.2 c) :- In this kind of layout identical modules perform similar processes in parallel and is likely to result in some redundant capacity.

(iv) Cellular Layout (Fig 1.2 d):- It is an extension of group technology concept where each cell is dedicated to a certain group of workpieces. In emergencies there is some scope for machining work pieces in a cell other than that intended.

Some of the automated material handling devices that are frequently seen in FMS are listed below along with their merits

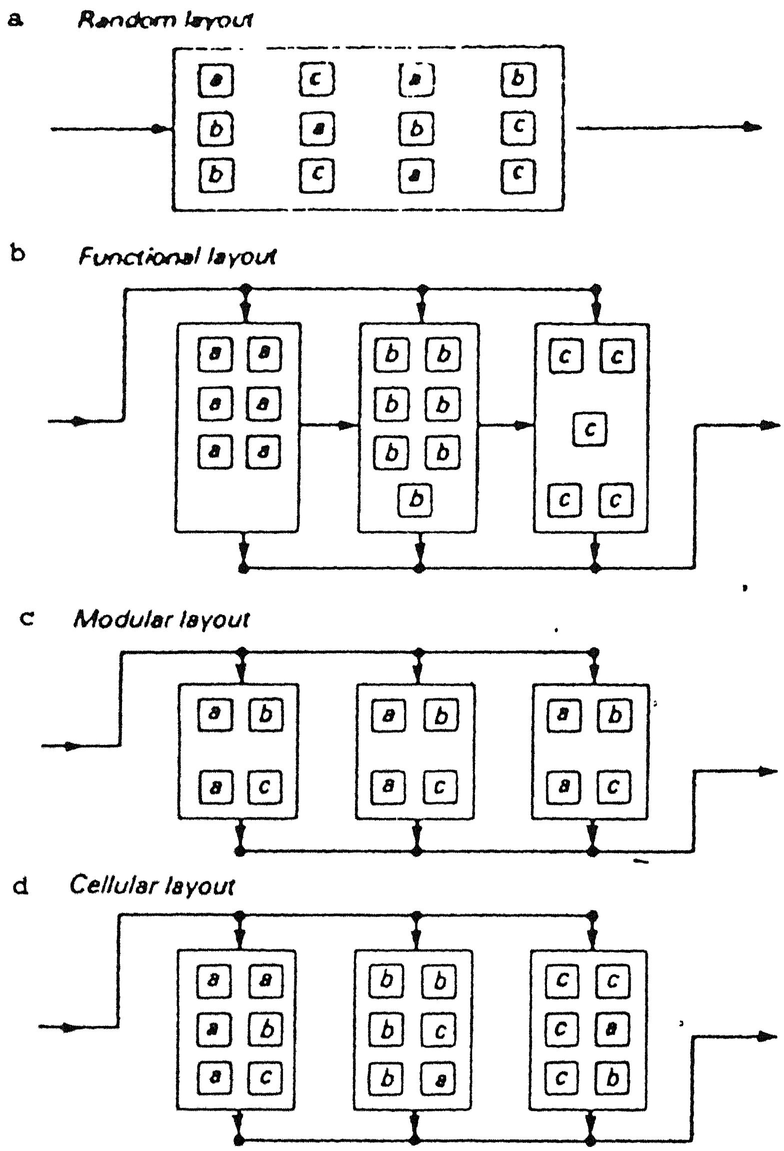


FIG 1.2 ALTERNATIVE LAYOUTS FOR FMS

and demerits.

(i) Conveyors :- Conveyors occupy a lot of space and are a limitation on any FMS. Further once a conveyor system is set up, it will be difficult to change the layout.

(ii) Overhead Cranes :- The blank carriers are loaded by robot and are then carried by a crane to a buffer area in the aisle between the machines, or direct to the magazine carrier at the machine. This is a simple and flexible system because there is a plenty of room in the aisle for blanks and handling can be completely mechanized.

(iii) AGV :- Free ranging AGV's which require no tracks are ideal for FMS. However, the AGV's are usually under-utilized.

1.5.3 PALLETS AND FIXTURES

Pallets and Fixtures have a critical influence on the performance of an FMS. If there are too few in the system then unmanned operation will be possible for short periods only; if there are too many then the cost is increased and the storage can become complicated.

The choice of pallets start with the work piece to be processed. Although the pallets are generally of standard design, their size depends on the machines, which in turn depends on the size of the work pieces. However, the situation with fixtures is far more complex. With very large work pieces such as machine beds or turbine housings standard fixtures can normally be used for each work piece. On the contrary where fixtures are designed to carry many small work pieces they are usually special to one or two components. Thus it is easy to end up with an enormous amount of

fixtures. For example, a system with three large and six small machining centers processing large and small work pieces could easily require 400 pallets and over 3000 fixtures if design was haphazard [5].

1.5.4 TOOLS

Management of tools in an FMS is just as critical as management of flow of work pieces. The way in which the tool changing is handled can affect the layout. With an FMS of ten machine tools there may be 3000-5000 tools in the system. Spending too less money may lead to too much manual intervention while in all other areas the system may be able to operate unmanned for a considerable time. Thus resulting in a lower utilization than expected as the plant will experience a lot of idle time as machines waits for the tools to be renewed.

Both the number of tools in use and the time spent in tool changing need to be kept at the minimum and, therefore, an appropriate tool management system must be built to aid the FMS. It is equally important to know how long the tools in use will last before they need renewing and whether suitable replacements are available.

'.6 OBJECTIVE AND SCOPE OF THE WORK

he above discussion highlights the presence of production lanning problems in designing an FMS. In particular, the cheduling problem and the tool management require special onsiderations. There are certain peculiarities of scheduling

problems related to FMS environment. For example, the scheduling in FMS involves not only scheduling parts but also tools, fixtures, pallets and material handling equipments. Therefore, in the present work, a generalized scheduling problem incorporating all the above elements and the tool management aspects of FMS are considered. A new heuristic has been proposed and the results are compared with some of the existing rules. A graphic interface has been developed for the display of schedule and resource utilization on a real time scale.

1.7 ORGANIZATION OF THE THESIS

Some work has been reported on the development of computer based system for scheduling in FMS. A detailed review of the literature is presented in Chapter II.

Chapter III deals with the system modelling and methodology used. A brief system description is presented at the beginning of the chapter which is then extensively discussed in separate sections. Algorithms used are also explained in this chapter.

Chapter IV gives the implementation aspects of the system. System domains, predicates and operators used are discussed in detail followed with a brief introduction on various program files created.

In, Chapter V, the results for proposed heuristic are compared with the existing rules using three sample examples.

Conclusions and suggestions for further improvements over the present system are presented in Chapter VI.

CHAPTER 2

LITERATURE SURVEY

The general n jobs and m machines job-shop problem is in itself a fascinating challenge. Although it is easy to state, and to visualize what is required, it is extremely difficult to get an optimum solution. Scheduling becomes much more complicated in FMS due to

- *Increased demand for utilization of manufacturing resources.*
- *Alternate routing of jobs becoming available.*
- *Increased number of system variables because of the introduction of new resources such as fixtures, pallets and material handling devices.*

2.1 APPROACHES TO SCHEDULING IN FMS

Two main approaches used for solving scheduling problems in FMS are

2.1.1 OPTIMIZATION TECHNIQUES

The three basic approaches used for scheduling in FMS using optimization techniques are :

a) Queuing Theory : *Queuing models account for the dynamic and uncertain nature of FMSs on an aggregate basis. They are probably most useful in the system design phase or possibly as rough approximations of the likely consequences of a given action since solution can be obtained very quickly on a computer [6].*

b) Perturbation Analysis : It uses actual operations data that is obtained from FMS computer to observe the effect of minor changes in the system on FMS performance. The major disadvantage of this type of analysis is that it cannot accurately predict the effects of large changes in the systems scheduling rules or design parameters.

c) Simulation : It has been used to represent the actual movement of individual parts through the system.

2.1.2 EXPERT SYSTEMS

An Expert System is a computer program that uses knowledge and inference techniques to solve problems that are usually solved with human expertise. An expert system stores a large body of facts; along with rules about how these facts can be used to solve problems. This collection of knowledge is called a knowledge base.

Five approaches that can be used to develop an expert system are discussed below [7] :

a) Hierarchical : The overall scheduling problem is solved at various levels of abstraction. The search space is reduced at various levels from aggregate schedule to detailed schedule.

b) Non-hierarchical : Here the schedule is developed without problem decomposition. The main disadvantage of this approach is that the search space can become very large and the importance and level of detail of the data are not considered.

c) Script-based : In this approach, basic schedule frameworks (skeletons) are stored in a database. They can be called from

the database rather than generated for each situation.

d) **Opportunistic** : In opportunistic approach the current decision and observations provide suggested opportunities for scheduling and the subsequent decisions are based on the selected opportunities.

e) **Constraint-directed** : This approach can be viewed as a heuristic search technique in which domain knowledge is represented as constraints that both bound and guide the search for a feasible solution.

2.2 SOME INVESTIGATED ISSUES

Some of the AI approaches which have been applied in the manufacturing context are discussed in this section. Bullers et. al. [9] use a subset of first-order-logic (FOL) called Horn clauses as the knowledge representation scheme and a resolution-type theorem prover as the control strategy. This approach has been used in the paper to address manufacturing planning and control problems such as the Part Mix, the Part Entry and Assignment, and the Process Selection problems.

Kusiak [8] has proposed an artificial intelligence and operations research approach to modelling flexible manufacturing systems. The machine layout problem and scheduling problem are considered as two sample problems to demonstrate the approach. Further, the authors have presented a formulation of the grouping problem in FMSs on the following lines :

Formulation : Determine machine cells, for each machine cell, select a part family consisting of parts with the maximum

production costs and select a material handling carrier subject to the following constraints :

Constraint C1 : processing time at each machine is not exceeded.

Constraint C2 : upper limit on the frequency of trips of material handling carriers for each cell is not exceeded.

Constraint C3 : number of machines in each cell does not exceed its upper limit.

Constraint C4 : some machines have to be included in the same machine cell because of technological requirements.

In the scheduling problem, a goal schedule is first obtained in an off-line mode by solving the optimization model which has to be developed for the FMS. The objective is to schedule resources of the machining system such as : parts, machines etc. in a way that the deviation between the goal schedule and the current schedule is minimized. Further, the author has advocated that both AI and operations research techniques can be used together and hold potential for attacking many of the FMS problems.

Kusiak [7] has proposed two distinct approaches for designing expert scheduling systems in a flexible manufacturing environment. These are :

a) Goal-based approach : In this approach, the scheduling problem can be formulated as follows: Given the goal schedule, schedule resources of the machining system - such as parts, machines tools, fixtures and pallets - in such a way that the deviation between the goal schedule and the current schedule is minimized.

b) Model-based approach : - The model-based approach to the

design of scheduling systems can be implemented in a number of ways. The author has proposed a model and an algorithm for the implementation of this approach. To give an idea of the nature of the expert system developed, two sample rules as proposed are given below :

Rule 1:

IF parts P_i and P_j use fixture F_k THEN they should be scheduled at least t units of time apart so that one of these parts can be unloaded from the fixture F_k.

Rule 2:

IF part P_i is to be dispatched for machine M_b which is occupied by another part P_j THEN check availability of an alternative machine M_a.

A computer based system for production scheduling in a dedicated FMS has been developed by De [10]. The system consists of three components : (i) a knowledge base, which describes both the current task domain situation and the goal to be achieved; (ii) a set of operators that are used to manipulate the knowledge base; and (iii) a control strategy to decide which operators to apply next and to resolve conflicts.

The system has been implemented using XLISP programming language. The model presented and illustrated with the help of an example considers machines and jobs with linear precedence constraints.

An approach to " A Multi-Pass Expert Control System" (MPECS) for manufacturing cell control is presented by Wysk [11]. MPECS is a modular stand-alone control system. The main purpose of MPECS is to : 1) utilize all the data available in a computerized

manufacturing cell, 2) create 'good" strategies to guide the system and 3) generate real time responses to make control decisions during system run-time. Operational information and material requirements are supplied by the factory control system. The managerial objectives such as due dates, cycle time and cost constraints are also input to the system. The feedback to control system include the information such as : a certain order is finished, additional material is required, a certain order can not be made by a specific due date, etc.

Fox and Smith [12], have proposed an expert system for automatic generation of job shop schedules via constraint directed search technique. The suggested system provides the user the capability to construct and alter schedules interactively. The authors claim that work is currently underway where the emphasis is on giving constraints an even more active role in the reasoning process.

Effective representation of domain-specific knowledge has been viewed as the key to knowledge based system (KBS). This includes the description of individual objects, classes of objects, and their relationships to one another. In the FMS production planning context, this involves representing knowledge about jobs, tasks (operations), and resources such as machines, tools, pallets etc. and their interrelationships. De [13] has attempted to develop a knowledge based system for making production planning decisions. In particular, knowledge representation based on frames is examined in the context of production planning and scheduling in FMS. Research issues beyond

knowledge representation which must be addressed in developing knowledge-based systems are also discussed.

Kusiak [14] has proposed a structure of expert system for the decision making in manufacturing industry. Essentially, his expert system controls three subsystems : process planning, programming of robots and machines and production planning. A scheduling framework together with the heuristic scheduling algorithm are developed.

Stecke and Solberg have modeled Caterpillar's FMS plant in Peoria, Illinois [15] and have found that a parts loading rule based on the ratio of the next operation's time to the part's total machining time out performed the plant's existing scheduling rule and a set of rules commonly used in job shops. However, this part loading rule did not work as well in another similar study done at John Deere FMS plant in Waterloo. The two heuristic loading rules they found to be most effective were the "'smallest proportion of jobs launched" and the "next empty pallet" rules.

CHAPTER 3

SYSTEM MODELLING AND METHODOLOGY

An FMS is a complex system with many hardware and software components and limited resources like machines, tools, pallets etc. Scheduling in an FMS is much more difficult than for assembly lines and job shops because (i) Each machine is quite versatile and capable of performing many different operations, (ii) the system can machine several part types simultaneously and (iii) each part may have alternate routes through the system.

In this chapter an expert system to provide decision support for (i) production scheduling and (ii) tool management, has been developed. The scheduling decision is concerned with the flow of parts throughout the FMS. The information requirements for scheduling are satisfied primarily by the decisions made at the planning stage. It includes the information about (i) jobs, (ii) number of machines of each type, (iii) number of fixtures of each type, (iv) number of pallets of each type, (v) number of material handling devices of each type and (vi) the tools.

3.1 SYSTEM DESCRIPTION

The entire system is divided into the following five basic modules:

(i) FMS Environment Information Input Module.

(ii) Shop Status Recognition Module.

(iii) Scheduling Module.

(iv) Tool Management Module.

(v) Graphical Interface and Evaluation Module.

The scheduling module and the tool management module run in parallel. A dynamic workpiece scheduling environment has been considered for decision making concerning the allocation of components to the various machines/cells. The decision making process is invoked when there is completion of any of the currently performed operations. Fig 3.1 gives an overview of modules for scheduling system.

3.2 ASSUMPTIONS

The system has been designed under the following assumptions :

(i) The machine tools do not fail while processing.

(ii) A particular machine can not process more than one part at a time.

(iii) FMS layout is not considered.

(iv) Material handling time considered includes only the secondary material handling time since primary material handling as such does not influence the model.

(v) No machine waiting occurs on account of non availability of tools.

(vi) An operation once started, must not be interrupted in between (no pre-emptive priorities).

(viii) Unload and load time are independent of machine-pallet-fixture combination.

(ix) Set up time is negligible.

(x) Tool life and other parameters are deterministic.

(xi) Any combination of alternate machines, pallets and fixtures given in operation specification is feasible.

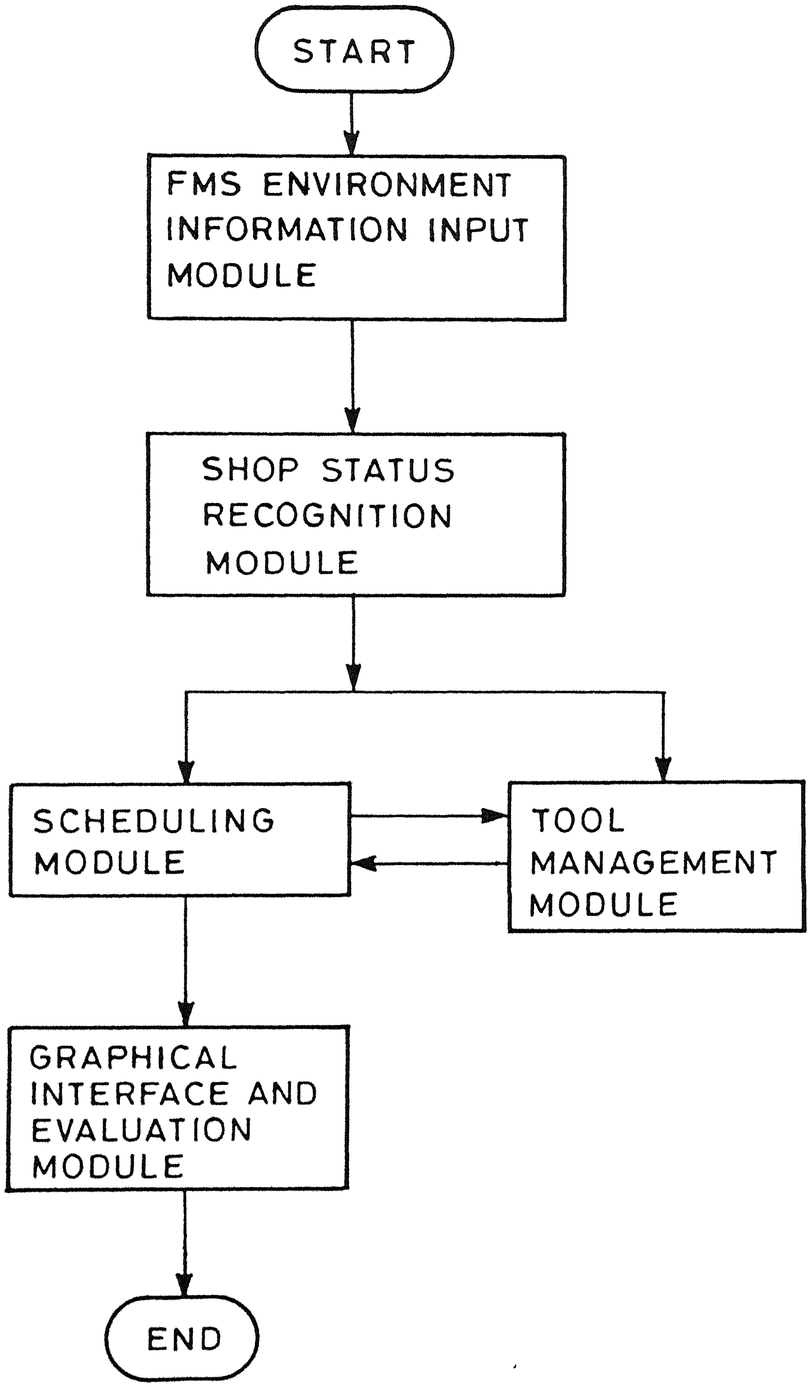


Fig. 3.1 Scheduling modules overview.

(xii) The job arrival pattern is assumed to be static, i.e., all jobs to be scheduled are available at the beginning of a shift.

3.3 FMS ENVIRONMENT INFORMATION INPUT MODULE

A complete factory environment has been considered for the design of the expert system where all the relevant informations regarding machines, pallets etc. are available from the planning stage. However, this module provides facility to add, delete or modify this information which is stored in a static database. The environment as envisaged for the design of the system is shown in Fig. 3.2.

The various parameters of a job that are described explicitly in this module are briefly discussed below :

(i) **Job** : A job is completely defined by a list of operations. The system design is in such a way that new jobs can easily be added with various feasible permutations and combinations of the operations.

(ii) **Batch Size** : The assumption that the machine set up costs are zero, would justify a batch size of 1. However, a batch size greater than one is no constraint to the system as it splits a batch size of 'n' into n equal and identical jobs with exactly the same resource requirements.

(iii) **Material Handling Time** : Time for the secondary handling system i.e. to orient and locate the work parts for processing at machines is incorporated in the system. Further, it has been assumed that the secondary handling time for each operation of a job is the same and independent of machine-handling device

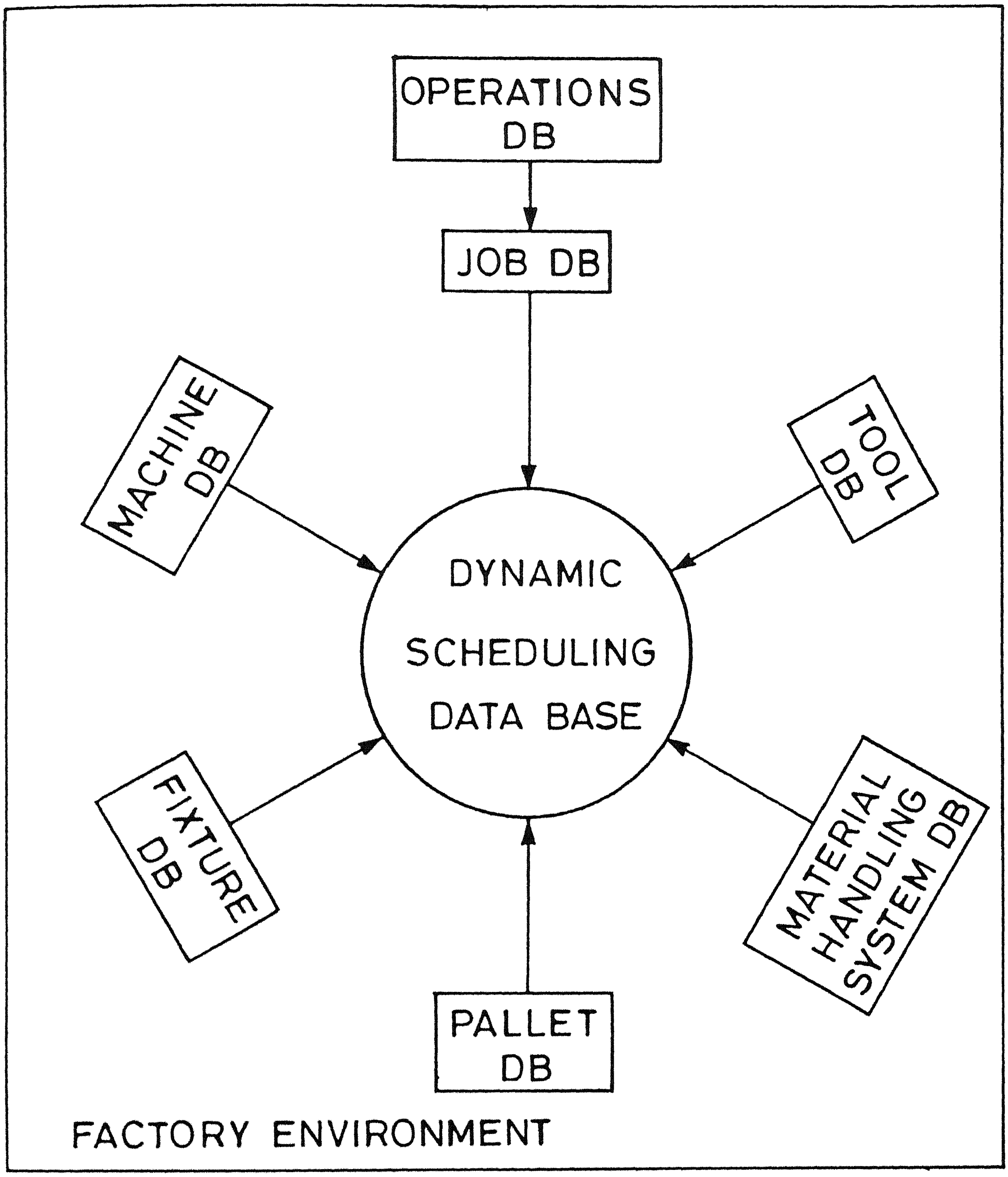


Fig. 3.2 Data base related to scheduling in FMS

combination.

*(iv) **Load Time and Unload Time** : These are specified for a job as most of the time they are a function of part size and geometry.*

*(v) **Precedence Constraints** : The jobs that need to be scheduled for operations by a set of machines and other resources may have a non-linear precedence constraint among the operations of each job.*

*(vi)**Set of Operations** : A list of all operations performed by machines is stored in the operation static data base as shown in Fig.3.2. An operation is described by a code name and resource requirements list. The alternate machines, pallets, fixtures and material handling devices that can be used for an operation of a job are explicitly mentioned.*

*The machining time may vary from machine to machine for the same operation. Hence, a process time deviation list is also provided along with the alternate machine list. The deviation is calculated over the machining time on the most preferred machine for the operation. The preference for the machine may be determined by the cost of operation, tolerances required or any other suitable criteria. The most preferred machine is the **first machine** mentioned in the alternate resource list. Thus the deviation in process time can be negative, positive or zero.*

*(vi) **Tools** : A set of tool required for an operation is defined in the form of a list.*

*(vii) **Process Time** : It is the processing time that an operation will take if performed on the most preferred machine.*

The other databases related to scheduling in FMS as shown in

Fig.3.2 are :

(i) **Machine Data Base** : It carries information on all the machines available on the shop floor. Capacity of machine tool magazine is a critical parameter specified in this data base.

(ii) **Pallet and Fixture Data Base** : All pallets and fixture types with their respective quantities are specified here.

(iii) **Material Handling System Data Base** : Secondary material handling systems specification are stored in this data base.

(iv) **Tool Data Base** : A tool data base comprises of all the tools that would be required for processing existing parts in the system. The predicted tool life and the minimum actual cutting time before replacement in terms of percentage of predicted life are specified here. The individual tool life can be determined by using the post operational experiences. However, this statistical data and quality of machined components must be subjected to frequent reviews and the tool data stored in the computer must be up-dated on a regular basis. Fig 3.3 gives the details of procedure for creating factory environment.

3.4 SHOP STATUS RECOGNITION MODULE

The factory environment provides a complete list of jobs (operations) that can be manufactured with the installed machine tools and the available resources. However, the parts that are launched into the system may vary from time to time due to fluctuations in the market demand and the management decisions. Further, all the alternate machines or resources as mentioned in the alternate resource list may not be available at a given time either due to breakdown or pre-occupation. Thus, every situation

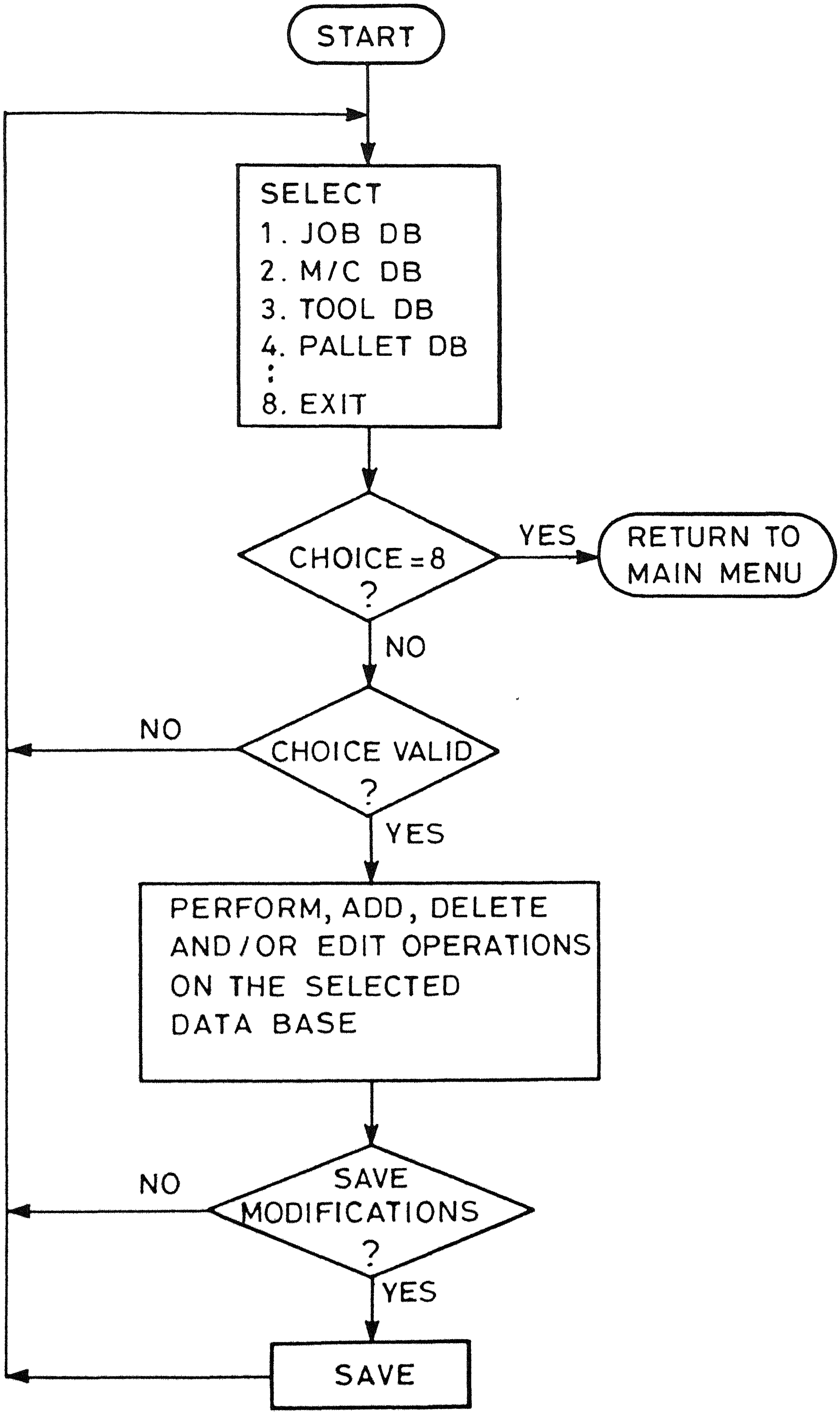


Fig. 3.3 Flow chart for FMS environment information input.

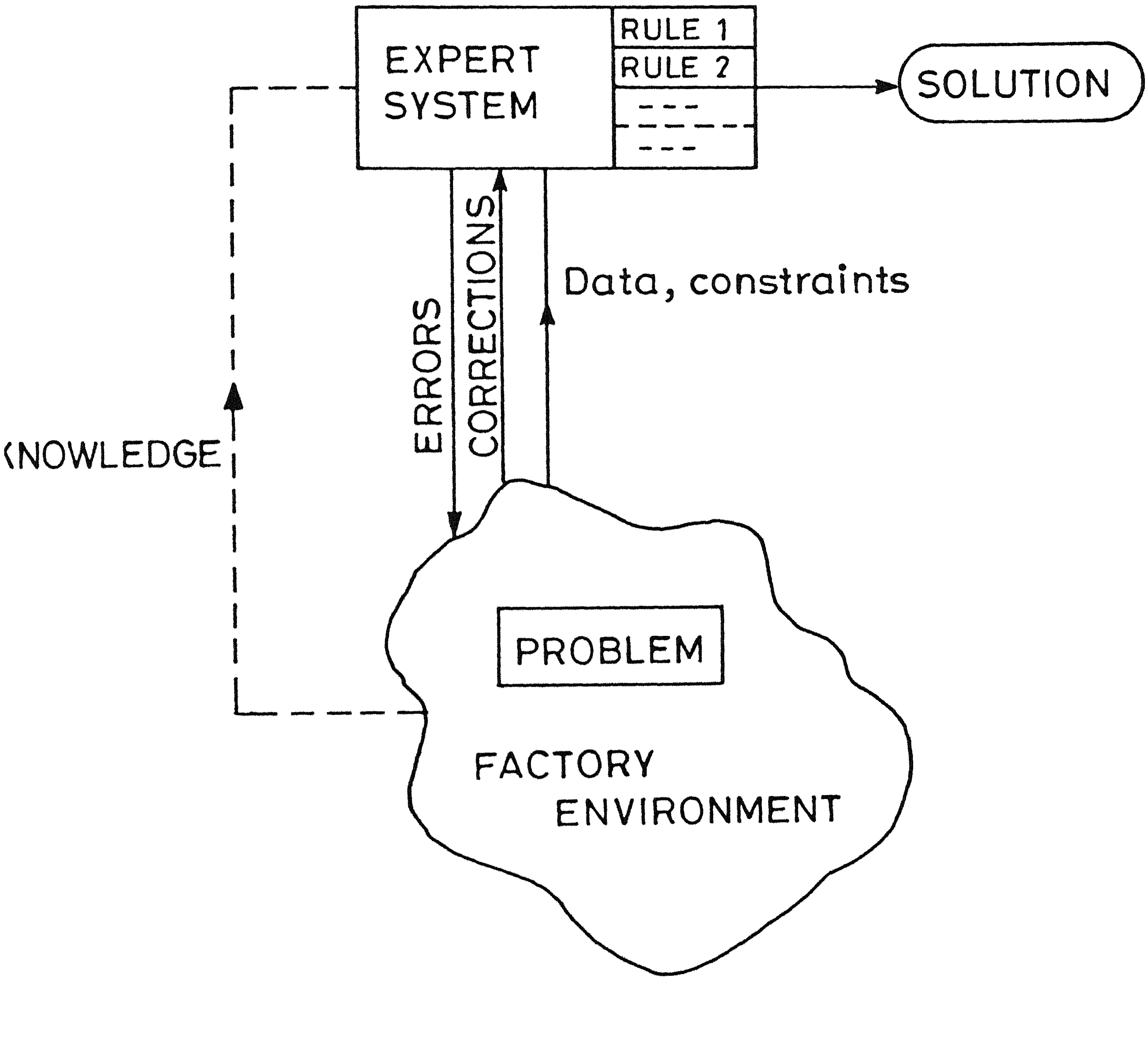


Fig. 3.4 Flow of data and constraints.

gives rise to a new scheduling problem. Fig. 3.4 shows the flow of data and constraints between problem environment and the expert system.

Shop status recognition module is used to structure a specific problem by selecting all or some of the alternate resources. In built in this module is a problem analyzer which ascertains that at least one feasible route exists for scheduling of every job in the problem domain. If it comes across with any discrepancies the same are displayed to the user for necessary modifications. The scheduling of jobs is not undertaken unless there exists at least one route for each job. In Fig 3.5, the various steps involved in this module are explicitly stated in the form of a flow chart.

3.5 SCHEDULING MODULE

The problem under consideration is to schedule n jobs concurrently, to detect resource conflicts, to determine alternate routes for a given part, if any, and to analyze schedule. The system static knowledge data base consists of four scheduling heuristics including the one proposed by the author. The remaining three heuristics are i) Shortest Processing Time (SPT), ii) Most work remaining (MWKR) and iii) Maximum Number of Operations Remaining(MOPR). The first and the second heuristics have been used by De [10] for developing his expert system. Whereas, Kusiak [14] has used SPT for the system developed by him. These three rules are describes as follows :

1) SPT : (Shortest Processing Time) Select an operation with the shortest processing time.

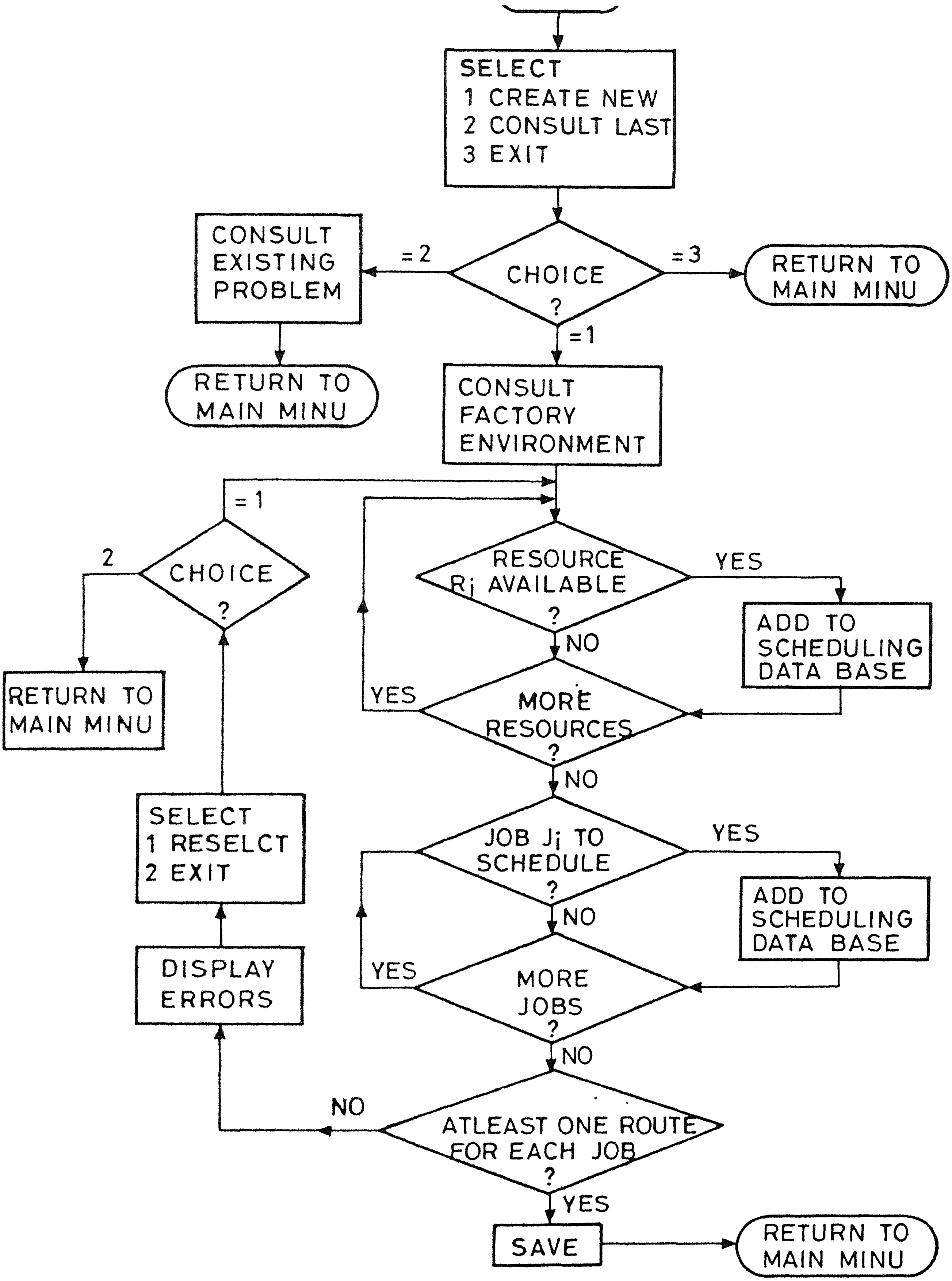


Fig. 3.5 Flow chart for shop status recognition.

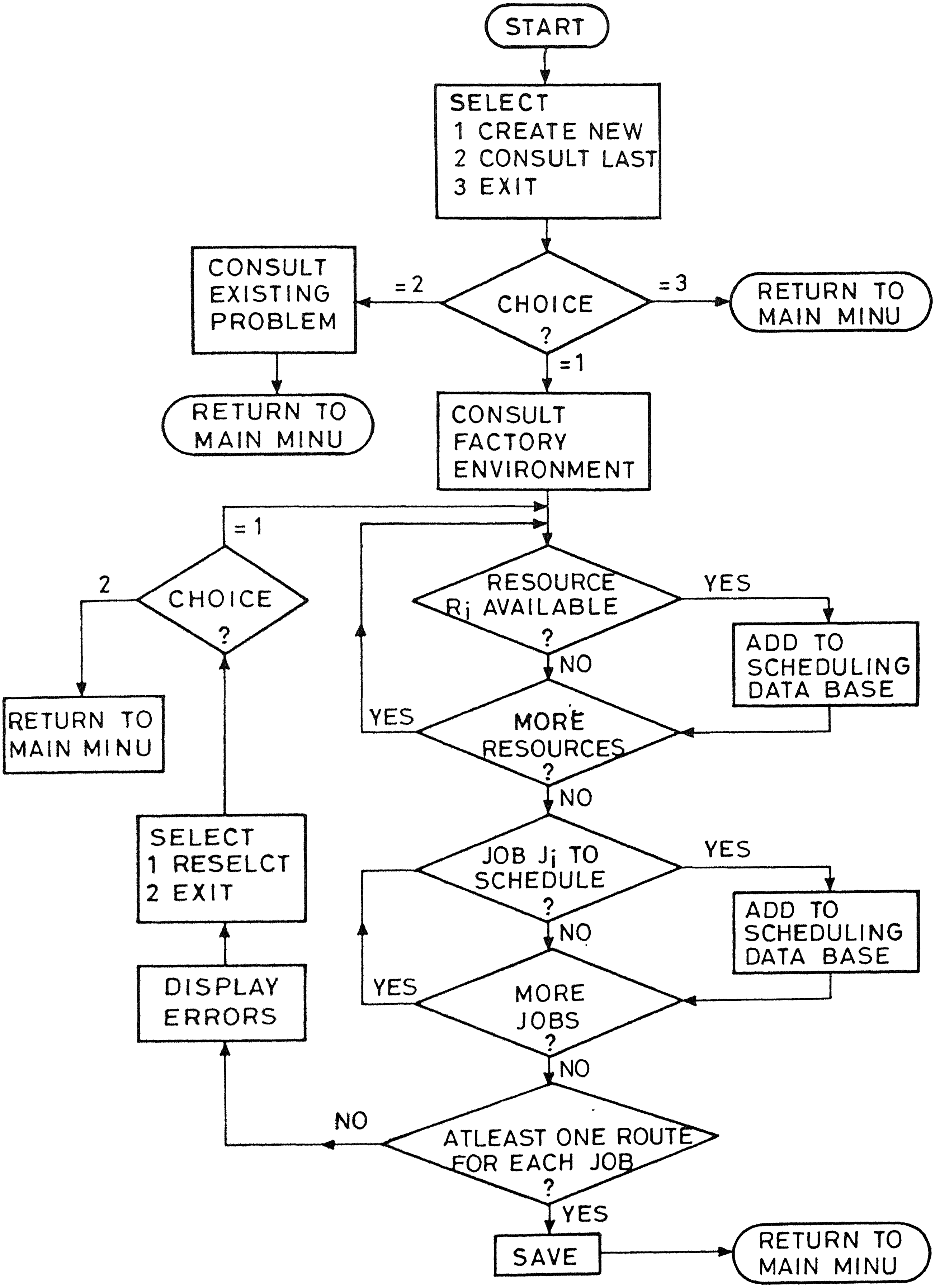


Fig. 3.5 Flow chart for shop status recognition.

2) MWKR : (Most Work Remaining) Select an operation that belongs to the job with the greatest total processing time remaining.

3) MOPR : (Most Operations Remaining) Select an operation which belongs to the job with the greatest number of operations still to be processed.

The reasons for selecting rules is not hard to understand. Using the SPT rule finds an operation which monopolizes a machine for the least time and, hence, perhaps constrains the whole system least. The MWKR rule is based on the notion that it may be best not to get too far behind on a particular job. Finally, the feeling that the delays in scheduling derive from the change-over of jobs between machines suggests that one should hurry through the jobs with the most change-overs left, hence the MOPR rule.

Schedules can be generated and analyzed by using one of these heuristics. The choice of heuristic would, however, depend on the objective. If the objective is to minimize the make span or equivalently the mean flow time then, SPT is one of the suitable choices.

Fig. 3.6 gives the organization of the system as conceived. Arrows denote information flow between the modules, knowledge base and the user.

A scheduling algorithm has been developed where the inference engine of the expert system is invoked at the time of any change in the shop status. The following are the various steps of the scheduling algorithm :

STEP 1 :

IF a job batch size is > 1 split it into n equal jobs

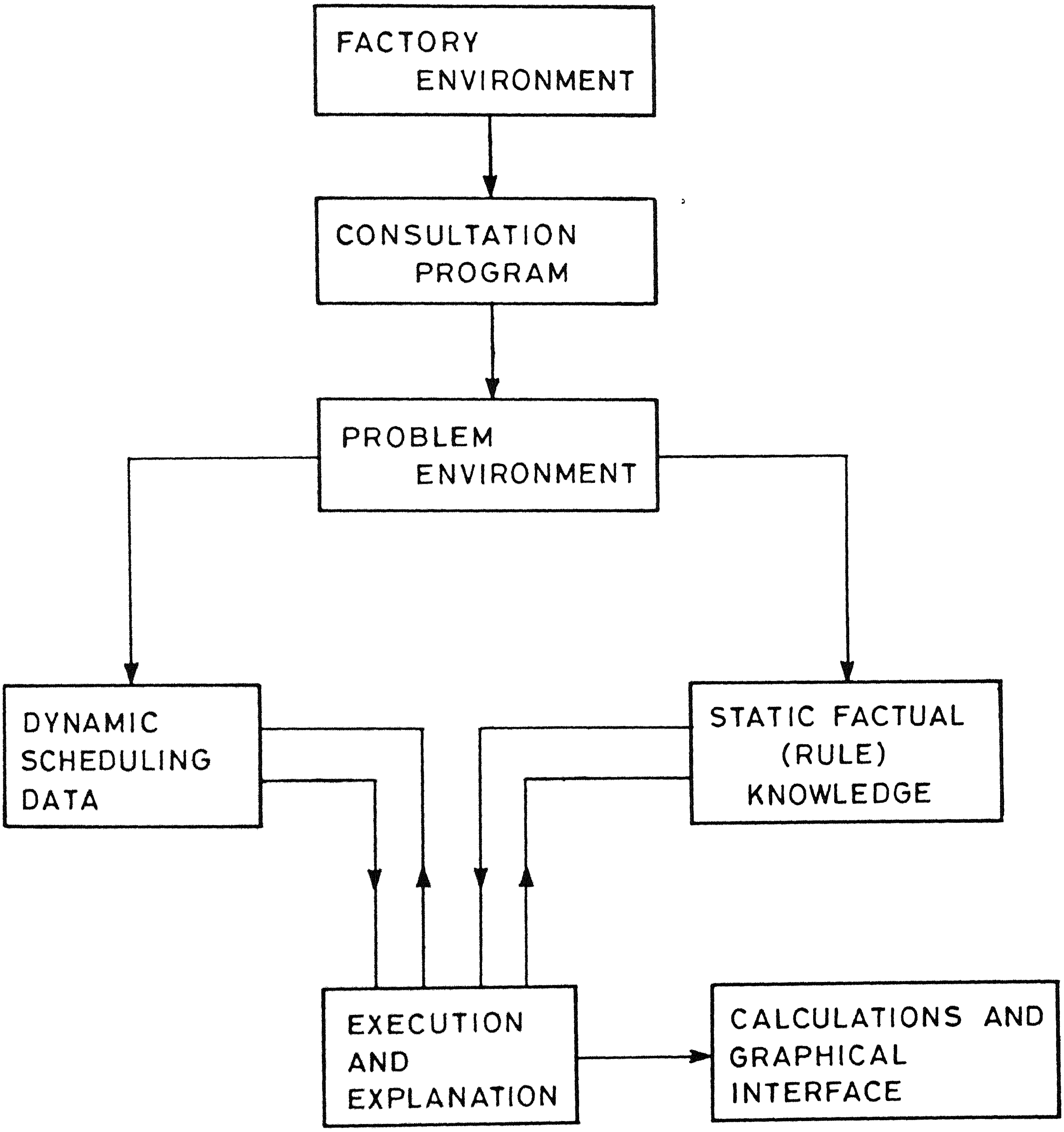


Fig. 3.6 Organization of the system.

STEPS 2 :

Maintain a feasible list of all the operations of each job that are schedulable on one of the machines in FMS.

STEP 3 :

From the list of feasible jobs select the one which has the most favorable value for the criterion selected by the scheduler.

STEP 4 :

Check if the most preferred machine is available for processing, if yes go to Step 6.

STEP 5 :

Check if there exists an alternate machine for the operation if Yes, then ask scheduler about his willingness to load the job on an alternate machine. In case reply is No goto Step 9.

STEP 6 :

Determine if the job is schedulable subject to availability of the following basic equipments (alternate equipments)

- fixture
- pallet
- material handling equipment

If the job is schedulable go to the tool management module and return to Step 7, else go to Step 9.

STEP 7 :

Add the job to the final schedule, update resource availability criterion value, send instructions for movement of the job.

STEP 8 :

Check if any other operation of the same job has the same

precedence, if yes, then temporarily remove this operation from the feasibility list (as two operations can not be performed simultaneously on the same job at different machines).

STEP 9 :

Update the list of feasible jobs and check schedulability of remaining jobs (repeat Steps 3 to 8).

STEP 10 :

Determine the next instant when a job or jobs will be unloaded.

STEP 11 :

If there is an unfinished operation(s) on the unloaded job(s) carrying the same precedence as that of the most recent operation completed on the job unloaded, then add this operation to the feasible list of operations, else else add all operation(s) of the unloaded job(s), with next precedence, to the feasible list.

STEP 12 :

Reconsider job(s) for scheduling which could not be loaded due to scarcity of resources.

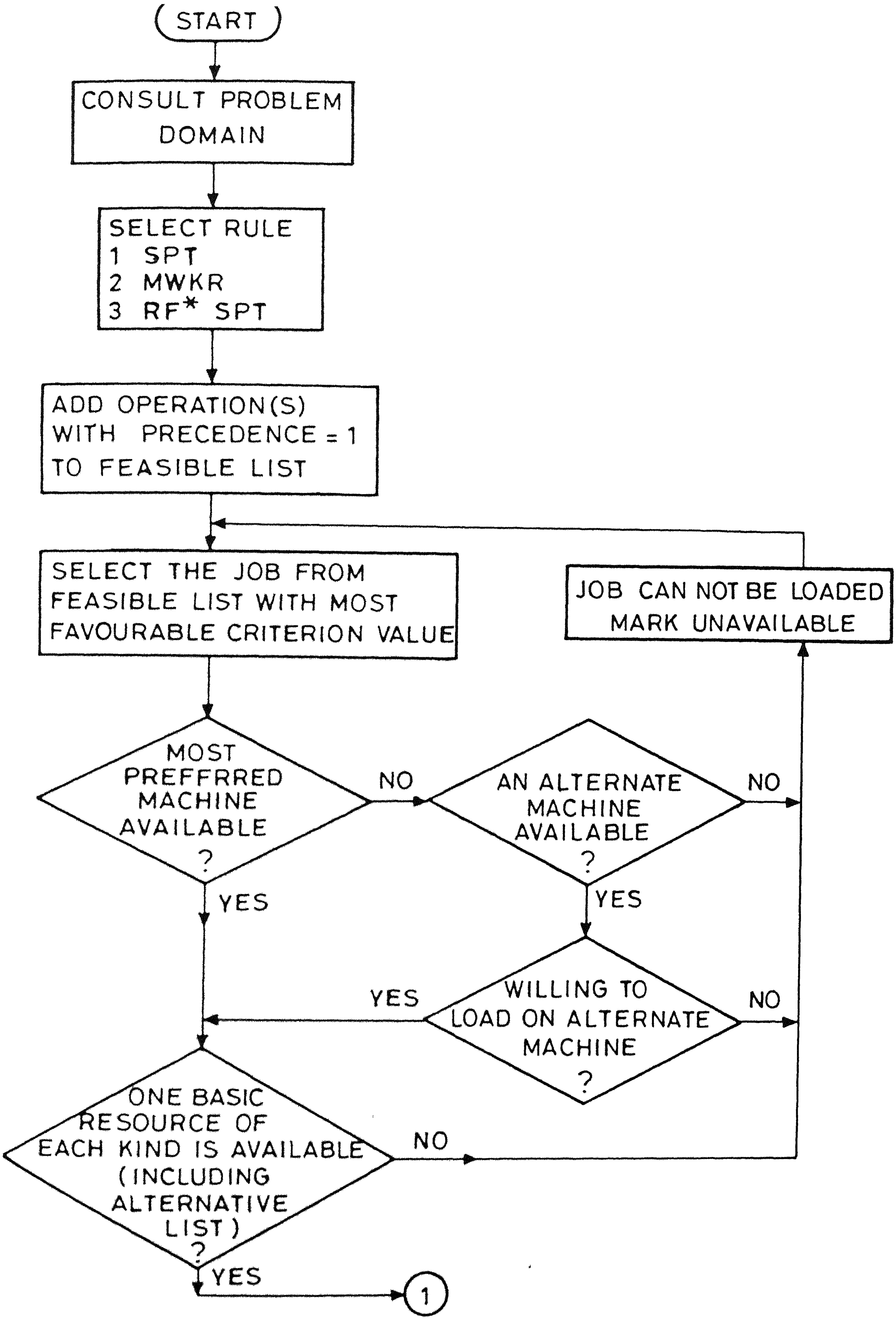
STEP 13 :

Update resource status and goto Step3. Continue till all the jobs are completed.

Fig 3.7 gives a flow chart for the scheduling algorithm described above.

3.5.1 THE NEW HEURISTIC

Almost all the loading heuristics that have been used in FMS scheduling were developed for conventional job shop environment.


START
CONSULT PROBLEM DOMAIN
SELECT RULE
1 SPT
2 MWKR
3 RF* SPT
ADD OPERATION(S) WITH PRECEDENCE = 1 TO FEASIBLE LIST
SELECT THE JOB FROM FEASIBLE LIST WITH MOST FAVOURABLE CRITERION VALUE
JOB CAN NOT BE LOADED MARK UNAVAILABLE
MOST PREFFRRED MACHINE AVAILABLE ?
NO
AN ALTERNATE MACHINE AVAILABLE ?
NO
YES
YES
WILLING TO LOAD ON ALTERNATE MACHINE ?
YES
NO
ONE BASIC RESOURCE OF EACH KIND IS AVAILABLE (INCLUDING ALTERNATIVE LIST) ?
NO
YES
1

CONTD ----

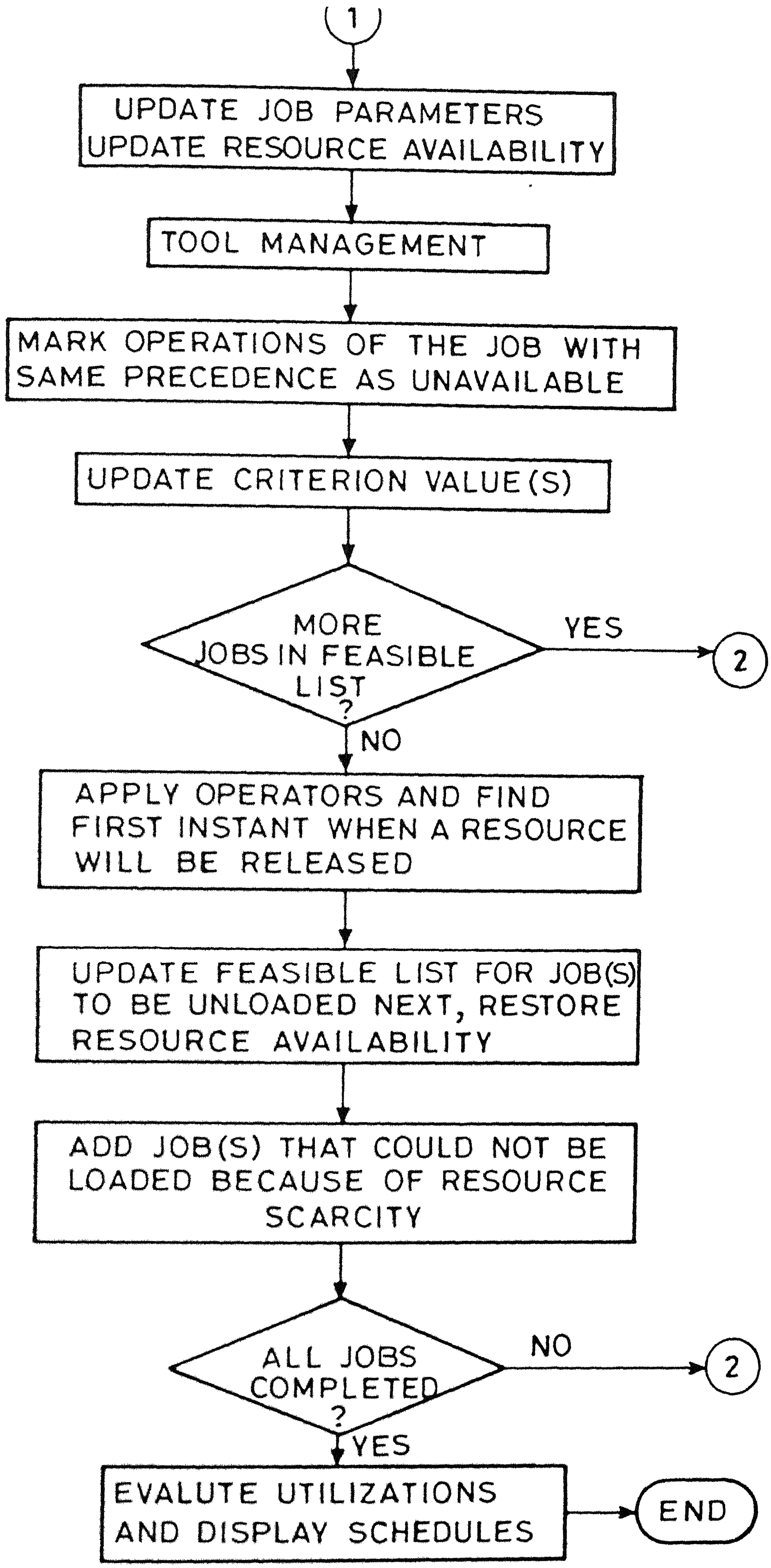


Fig. 3.7 Flow chart for scheduling.

These heuristics primarily consider the processing time, number of operations in a job and due date constraints. Although, a lot has been talked about flexibility in a FMS where alternate routes exists for jobs, no heuristic really gives any weightage to the alternate combinations of pallets, fixtures, material handling equipments and machines that are available for processing a job. Hence, there is a need to develop a heuristic which gives appropriate weightage to the flexibility available. For this purpose, we introduce the concept of Routing Factor (RF) which is defined below.

Routing factor, RF, is defined as the product of number of alternate resources of each type which can be used for the completion of an operation.

For example consider an operation Ojk that can be performed either on a machine Mi or Mj using pallet Pi or Pj, fixture Fi and material handling device Mhi then the routing factor is given by

R.F. = 2(machines) * 2(pallets) * 1(fixture) * 1(material handling device)

= 4

In case of an empty list of resources say no specific fixture, the multiplying factor for that resources is taken as 1.

The loading rule considered and coded for the system gives weightage to processing times in terms of routing factor. The feasible operation of any job with minimum weighted processing time is given higher priority for scheduling. The job with

minimum weighted processing time is in fact one which has minimum flexibility for scheduling.

The intuition behind such a weightage scheme is simple and straightforward. An operation which has a higher routing factor implies that there are more means for achieving the end. Thus by making use of maximum permissible alternate paths, not only one can minimize the makespan could expect to achieve higher average utilization of the various resources.

Similar rules can be devised and tested for their performance in FMS. For example, one could give similar weightage to remaining process time or flexibility may be calculated in terms of number of machines needed to complete a job etc.

3.6 TOOL MANAGEMENT

The subject of tool management needs to be considered in the same light as any other subsystem of an FMS. Among the major weaknesses in existing FMS are: i) too much manual tool changing at the ATC (automatic tool changers), and ii) inadequate use of standard preset tools. If manual tool changing is allowed in an unmanned operation, then the system effectiveness is affected adversely. The situation gets aggravated because FMS are capital intensive and they need to be operated for 16-24 hrs a day to give a good return on the capital. Therefor, all efforts become necessary to avoid/reduce wasteful and time consuming manual tool changing operations.

A tool management system which keeps tracks of tools, tries to

reduce the number of tools in use and the time spent in tool changing and knows how long the tools in use will last before they need renewing has been developed and implemented. The tool management system as conceived is shown in Fig. 3.8.

The algorithm used for tool managements system is explained below:

Step 1 :

Find the tool requirements for the job required to be machined.

Step 2 :

Determine all the required tools that are already there in the tool magazine and Repeat Step 3 to Step 6 for all the tools in magazine.

Step 3 :

If the tool under consideration has sufficient life to process the job then go to Step 6.

Step 4 :

If the tool needs renewing then send it to the tool room other send it to the local stocker (available on each cell).

Step 5 :

Check if there exist any tool in local stocker with sufficient life to process the job on machine. If there exists one then send instructions to load it on the tool magazine else request for a new tool.

Step 6 :

Update tool database.

Step 7

Determine all tools that are required for the processing of the job but are not available in the machine tool magazine.

Step 8 :

If tool magazine does not have adequate space to accommodate all these tools then remove all tools that are not required for the current operation and send them to the local stocker. Repeat Step 9 and Step 10 for all those tools that are not in the magazine.

Step 9 :

Check if there exist any tool in local stocker with sufficient life to process the job on the machine. If there exists one then send instructions to load it on the tool magazine else request for a new tool.

Step 10 :

Update tool database.

The various steps of the tool management algorithm are depicted in Fig 3.9.

Following are some of the major advantages expected out of the proposed tool management system :

a). Reduction of tool cost : Total number of tools in the system can be significantly reduced as the tools would be transported to individual machines only when they are required. This also results in reduction of the required tool magazine capacity of each machine.

b). Elimination of human Error : Conventional tool management is laborious and prone to human errors since large amount of tool data

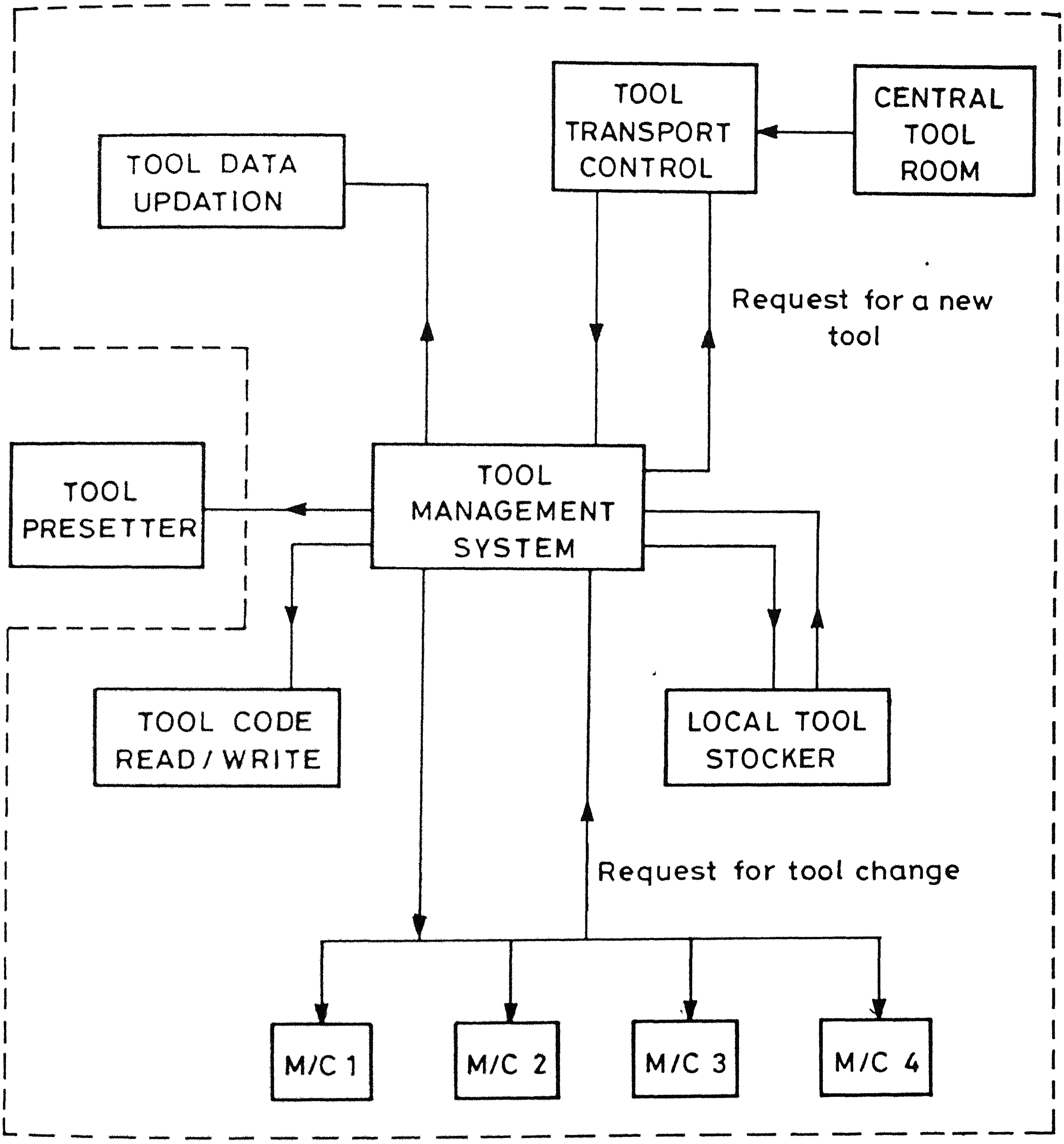


Fig. 3.8 Tool management system.

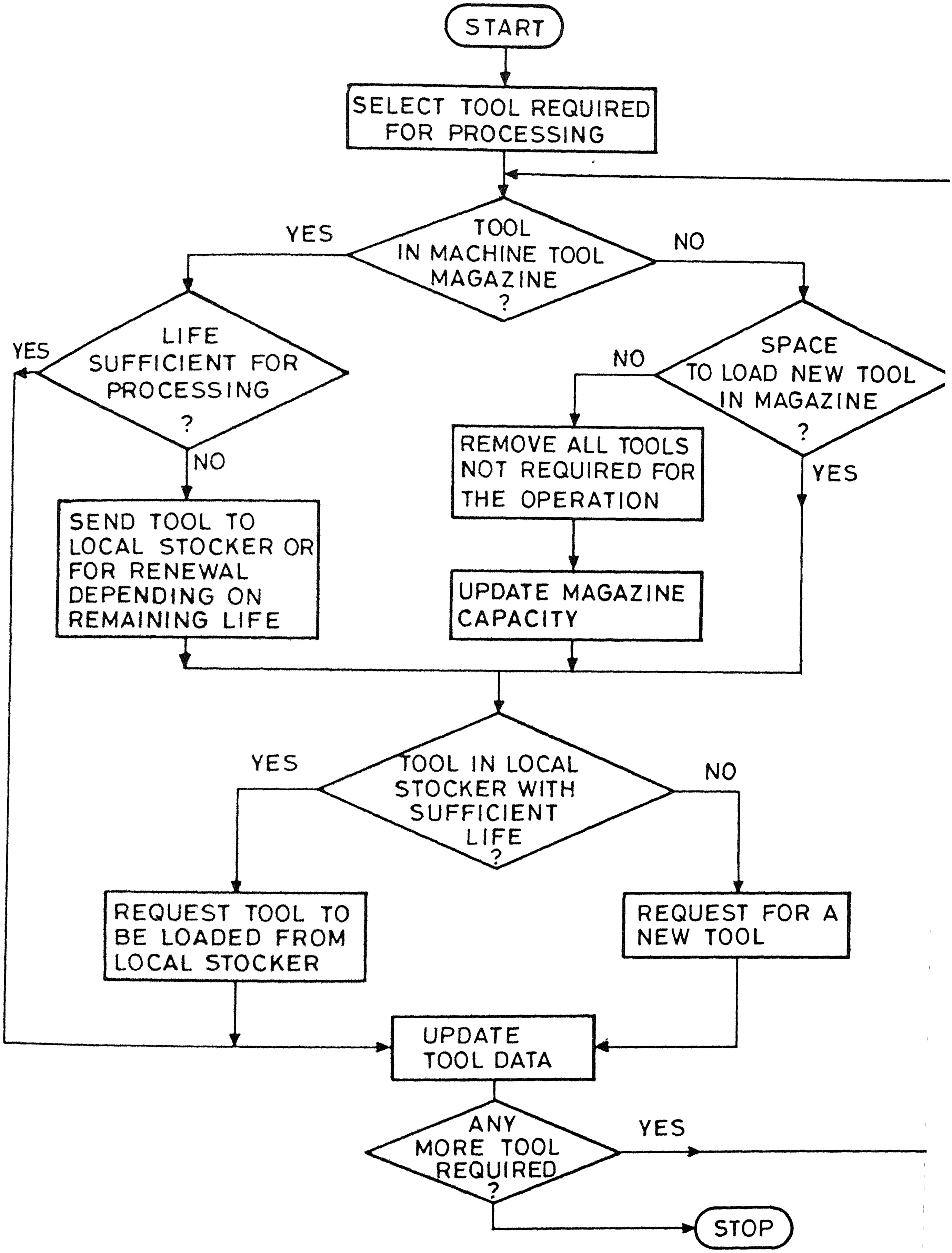


Fig. 3.9 Flow chart for tool management .

needs to be captured and recorded each time tools are loaded in the magazine.

c). Prolonged unmanned operations.

d). Quality : Quality of production would be significantly improved as tool change control is no longer dependent upon random manual intervention.

3.7 GRAPHICAL INTERFACE AND EVALUATION MODULE

The schedule thus generated is displayed in the form of a Gantt chart. It gives loading, unloading, machining and material handling time for each operation of the job. The utilization of various resources is calculated and shown on a real time basis. The flow times, wait times etc. are also displayed graphically.

CHAPTER 4

IMPLEMENTATION

The software for generalized scheduling and tool management in FMS has been written in Turbo Prolog (Version 2.0) and can be run on any PC-PC XT/AT machine. The graphics interface is also written in Prolog. This chapter gives an overview of the organization of software and different program files. The system implemented is menu driven and user friendly. Help on system is provided at various stages which can be invoked using help key "F1".

4.1 A WORD ABOUT PROLOG

Prolog was originally developed in 1972 by Alain Colmerauer and P.Roussel at the University of Marseilles in France. Almost all languages developed for the computer during the last few decades are known generally as procedural languages e. g. FORTRAN, COBOL, BASIC, PASCAL, etc. These are primarily numerical processors on the other hand, Prolog is an object oriented language which uses heuristics to solve problems. It is unique in its ability to infer (drive by formal reasoning) facts and conclusions from other facts. It has found wide applications in expert system, natural language processing, robotics, gaming and simulations.

Two major limitations of the Turbo Prolog are :

(i) The size of the system developed is limited by the amount of

memory available.

(ii) Turbo Prolog, like all Prologs, is inefficient for numerical processing.

4.2 THE STATE - OPERATOR FRAME WORK

The FMS scheduling problem can be viewed as a multistage decision problem in which values of decision variables define a state of the system and the state is constantly being altered during the solution process by changing one or more variables. This characteristic of changing the state through the change of variables is also central to the state operator frame work. Here, the state description is given formally, not as algebraic equations, but in the language of first order predicate calculus- - the legitimate expressions of this language are called well-formed formulas(wffs) [17]. Also, operators are defined which can change the state of system in specific ways. The knowledge base consists of the general descriptions of a state of solutions process, a fully instantiated state, and a set of operators that transform the initial state to the goal state.

The argument of the predicate could vary over the entire allowable range of the domain of the predicates. The domains of the predicates in FMS scheduling problem are given below.

4.2.1 DOMAINS

JOB : The set of jobs that needs to be scheduled.

OPERATIONS : The set of all operations performed by the machines.

MACHINE : The set of all machines in FMS

PALLET : The set of all pallets in FMS.

FIXTURES : The set of all fixtures in FMS.

HANDLING EQUIPMENT : The set of all material handling equipments in FMS.

TOOLS : The set of all tools in FMS.

TIME : The time domain.

STATUS : Availability or unavailability status of jobs or resources.

QUANTITY : Number of resources.

PRECEDENCE : The precedence domain.

BATCH : The set of batch numbers of a job.

4.2.2 NOTATIONS

i : Index for resources

b : Index for batch

j : Index for job

k : Index for operation

t : Index for time

M : Machine

T : Tool

P : Pallet

F : Fixture

J : Job

H : Material handling equipment

O : Operation

t : Time

Ri = A set of resources (Mi,Pi,Hi,Fi)

Some of the important predicates necessary to describe the state

of system are given below :

4.2.3 PREDICATES

JOBLIST([J1,J2,J3]) : Jobs selected for scheduling

OPERN_OF_JOB(J1,[Oj1,OJ2,Oj3]) : List of operations that constitutes a job.

OPERN_REQ_MACHINE(Ojk,[M1,M2]) : Operation Ojk can be performed on machine M1 or M2.

OPERN_REQ_PALLET(Ojk,[P1,P2]) : Operation Ojk requires pallet P1 or P2.

OPERN_REQ_HANDLINGEQP(Ojk,[H1,H2]) : Operation Ojk needs material handling equipment H1 or H2.

OPERN_REQ_FIXTURE(Ojk,[F1]) : Operation Ojk needs fixture F1.

OPERN_REQ_TOOLS(Ojk,[T1,T2]) : Operation Ojk needs a tool set (T1 and T2).

TRANSFER_TIME(Jj,Hi,t1) : It takes t1 units to orient and place job Jj with the help of material handling equipment Hi.

LOAD_TIME(Jj,Mi,t1) : It takes t1 units to load job Jj on machine Mi.

MACHINE_TIME(Jj,Ojk,Mi,t1) : It takes t1 units to process operation Ojk of job Jj on machine Mi.

UNLOAD_TIME(Jj,Mi,t1) : It takes t1 units to unload job Jj from machine Mi.

BATCH_SIZE(Jj,N) : Job Jj has N identical units.

SCHEDULE_RULE(NAME,CODE) : Rule selected for scheduling jobs is rule name (NAME='SPT') with assigned code (CODE=1).

FIRST_OPERN_OF_JOB(Jj,Ojk,PRECED) : Operation(s) Ojk is the first operation of job Jj if PRECED = 1.

NEXT_OPERN_OF_JOB(Jj,Ojk,PRECED) : Operation(s) Ojk is the next operation of job Jj if it's precedence (PRECED) is one more than that of the operation currently under processing.

LAST_OPERN_OF_JOB(Jj,Ojk,PRECED) : Operation(s) Ojk is the last operation of job Jj if there is no operation(s) with a precedence higher than the operation under consideration.

JOB_TO_SCHEDULE(Jjb,Ojk) : Operation Ojk of job Jjb is schedulable.

SELECTED_MACHINE(Jjb,Ojk,Mi) : Operation Ojk of job Jjb is performed at machine Mi.

SELECTED_PALLET(Jjb,Ojk,Pi) : Operation Ojk of job Jjb being performed using pallet Pi.

SELECTED_MHEQUIP(Jjb,Ojk,Hi) : Operation Ojk of job Jjb being processed using material handling equipment Hi.

SELECTED_FIXTURE(JjB,Ojk,Fi) : Operation Ojk of job Jjb being processed using fixture Fi.

TOOL_IN_MAGZINE(Ti,Mi,LIFE) : Tool Ti is in the tool magazine of machine Mi with expected remaining life "L".

TOOL_IN_STOCKER(Ti,L) : Tool Ti is in the stocker with expected remaining life "L".

In order to generate a production scheduling plan, operators have to be applied to effect a change of state. In general, an operator can be applied to a state if its required preconditions are met. The operator set that is necessary for our FMS scheduling problem is given below.

4.2.4 OPERATORS

ADD_FIRST_JOB(Jjk,Ojk,PRECED) : Adds all operation(s) of job Jjb

with PRECED = 1 to the feasible list.

MARK_NOT_AVAIL(Jjb,Ojk,PRECED,STATUS) : Marks all operations of Jjb having same precedence as that of Ojk as not available until selected operation Ojk is completed.

MARK_AVAIL(Jjb,Ojk,PRECED,STATUS) : Makes available for scheduling all operation(s) of Jjb having same precedence as that of Ojk after it's completion.

ADD_NEXT(Jjb,Ojk,STATUS,PRECED) : Adds operation(s) of job Jjb with precedence equal to PRECED + 1 to the feasible list after completion of all operation(s) with precedence = PRECED.

MOVE_JOB(Jjb,Ojk,Mi,t1) : Starts moving job Jjb for operation Ojk to machine Mi for processing at time t1.

LOAD_JOB(Jjb,Ojk,Mi,t1) : Loads job Jjb on machine Mi for processing operation Ojk at time t1.

MACHINE_JOB(Jjb,Ojk,Mi,t1) : Machine operation Ojk of job Jjb on machine Mi at time t1.

UNLOAD_JOB(Jjb,Ojk,Mi,t1) : Unloads job Jjb from machine Mi at time t1.

UPDATE_RES_CONSUM(Jjb,Ojk,Ri,t1) : Determine the remaining quantities of resources belonging to the set Ri for operation Ojk of job Jjb which is selected for processing at time t1. If the remaining available quantity is zero, then mark the resource Ri as not available for subsequent operations.

RELEASE_RESOURCE(JjB,Ojk,Ri,t1) : If operation Ojk of Jjb is completed at time t1 and was using a set of resources Ri then update the availability of the resources belonging to the set Ri.

ADD_TOOL(Jjb,Ojk,Mi,Ti,t1) : If tool Ti is not in the tool magazine of machine Mi at time t1 which is required to process operation Ojk of job Jjb then load a new tool.

UPDATE_TOOL_LIFE(Jjb,Ojk,tp,Mi,Ti) : If the tool Ti which is in the tool magazine of machine Mi, completes operation Ojk of job Jjb then update tool life by adding processing time of the completed operation.

REMOVE_TOOL(Jjb,Ojk,CAPACITY,Mi,Ti,Tj) : If tool Tj is not required by operation Ojk of job Jjb and there is no space in the machine tool magazine to load a new tool Ti which is required for processing the job then remove tool Tj from magazine.

RENEW_TOOL(Ti,L) : If the remaining life "L" of tool Ti is less than the minimum specified life to retain a tool in the system then send tool Ti for renewal.

The new database predicates are added or deleted from the list by using Prolog standard predicates like asserta, assertz and retract.

4.3 PROGRAM FILES

To generate a user friendly code and to have control over flow of data the following Prolog program files have been created

(i) CONTROL.PRO

(ii) LIST.PRO

(iii) MENU.PRO

(iv) WINDOWS.PRO

(v) HELP.PRO

(vi) FMS1.PRO

(vii) FMS2.PRO

(viii) FMS3.PRO

(ix) FMS4.PRO

(x) FMS5.PRO

(xi) INCON.PRO

(xii) RESULT.PRO

The functions performed by each of the above stated files are discussed briefly in the following text.

CONTROL.PRO : This is the main program which invokes all other subprograms. It starts with initialization of variables such as counters and displays the main menu. As per the user's choice the subroutines are called and executed. The completion of any subprogram brings back the user to this module for further execution until the program is forcibly stopped in between.

MENU.PRO : This program has been written to design a pop-up menu for software. The choices from the menu can be made either by moving the cursor with the help of "left", "right", "up" and "down" arrows followed by "Enter" key or by pressing the first character of the choice. This program is used in other programs wherever a need of selection through menu was desirable.

LIST.PRO : Program "List.pro" contains predicates and clauses for most of the list processing operations that can be performed in Prolog. The objective for designing this module was to have separate program on list processing which could be used in future also. Some of the list operations that can be found in this program are

(i) Append a list to another.

(ii) Add an element.

(iii) Delete an element.

(iv) Write all element of list.

(v) Find n'th element of list.

(vi) Find membership of list etc.

WINDOWS.PRO : This has been specifically designed for the screen formatting of the developed software. It, mostly, uses standard Prolog predicates for a set of windows for dialogue between the user and the program. As the needs of various modules are different, a separate set of windows for each subprogram have been created. All the windows of a set are removed as soon as the module is over because turbo-prolog can support maximum of 34 windows at a given point of time.

HELP.PRO : A help system similar to the one found in commercial packages has been created. The user can get into help by pressing F1 key and come out by pressing "Esc". There are two levels of help (i) help on overall system, (ii) help messages on specific modules. This program controls help at various module levels.

FMS1.PRO : This program contains the flow strategy for the control of FMS environment information input module. There are eight choices in the program and each of these choices are specifically meant for modification of one of the scheduling databases.

FMS2.PRO : It contains predicates and clauses to define a new

scheduling problem environment. User can define the resource availability by answering questions in yes/no form. The defined problem is stored in a file which can be referred on a subsequent run. This module is integrated with the job selection program (FMS3.PRO) and a minimum resource requirement program. The minimum resource requirement program checks that atleast one feasible path is available for the jobs to be scheduled. In case there is a situation where none of the alternate machines or other resources are available from resource selection module then appropriate messages are displayed and the errors can be resolved either by changes in the database or reselection of resources. However, provision for manual handling and non standard fixturing has been made by defining an empty list of the corresponding resources.

FMS5.PRO : A line editor has been provided to edit and modify screen help files and others.

INCON.PRO : It contains the loading heuristics and the execution predicates. New loading heuristics can easily be added by creating a new set of clauses of required predicates and operators. It also contains the predicates for tool management.

RESULT.PRO : This is a program for graphical display of the generated schedule and resource utilization. A general purpose program has been written which can cater for any number of jobs and resources. However, due to resolution limitations the maximum number of jobs and resources that can be used are

Job-Wise schedule (Flow-time) :

Max(Job)=25

Max(Machines)=50

Gantt chart :

Max(Job)=50

Max(Machines)=25

Utilization

Max(Pallets)=50

Max(Machines)=50

Max(Fixtures)=50

Max(Material handling devices)=50

Help Screen Files : A number of help screen files have been created to provide help to the user at different stages. These can be invoked by the function key "F1". Help has been provided on the general use of the system, error possibilities, individual modules and variable definitions. Following is the list of various help files :

(i) HELP1.SCR

(ii) HELP2.SCR

(iii) HELP3.SCR

(iv) HELP4.SCR

(v) HELP5.SCR

(vi) HELP6.SCR

(vii) HELP7.SCR

(viii) HELP8.SCR

(ix) ERRORHLP.SCR

(x) HELPGEN.SCR

CHAPTER 5

RESULTS

Schedules for three illustrative problems have been prepared and presented in this chapter. These examples have been constructed to show the various situations that the developed system can handle, viz, batch size greater than or equal to one, linear and non-linear precedence constraints etc.

5.1 EXAMPLE 1

This example is an illustration for scheduling problem with linear precedence constraints between operations of a job and batch size equals to one. Let us consider a shop floor environment where we have :

i) Three machines : M1(4), M2(4) and M(3).
Number inside the bracket indicates the machine tool magazine capacity.
ii) Three pallets : P1(1), P2(2) and P3(1).
Number inside the bracket indicates the number of pallets in the system.
iii) Three fixture : F1(2), F2(2) and F3(1).
Number inside the bracket indicates the number of fixtures in the system.
iv) Two material handling equipments : MH1(1) and MH2(1).
Number inside the bracket indicates the number of material handling equipments in the system.
v) Five type of tools : T1(135), T2(135), T3(70), T4(170) and

T5(70).

Number inside the bracket indicates the expected tool life of the tool.

Now, let us suppose that four different jobs each with a batch size of one are to be scheduled for the various operations. We refer to these jobs as J1, J2, J3 and J4. Further, the operations to be performed on each job and the order in which they must be performed are as follows :

J1 : 011 (1), 012 (2) and 013 (3).

J2 : 021 (1) and 022 (2).

J3 : 031 (1), 032 (2) and 033 (3).

J4 : 041 (1), and 042 (2).

The number inside the bracket indicates the precedence of operations.

Table 5.1.1 specifies the operation times for various operations on different machines. In the Table a blank against a machine indicates that the operation cannot be performed by the particular machine and "*" denotes the preferred machine on account of technological requirements such as surface finish, etc. among alternate machines.

The secondary material handling time (in minutes) required for each job is as follows :

J1 : 4

J2 : 5

J3 : 6

J4 : 4

The loading and unloading times (in minutes) of various

TABLE 5.1.1 : Operation Times on Various Machines

MACHINES	M1	M2	M3
OPERATIONS	(Machining	Time in	Minutes)
O11	28	27*	-
O12	-	-	22
O13	19	17*	-
O21	-	21	-
O22	24	-	-
O31	24*	-	25
O32	-	39	-
O33	19	-	-
O41	25	-	-
O42	-	27*	29

operations are as follows :

Operation : (Loading, Unloading)

O11 : (3,4)

O12 : (3,6)

O13 : (6,5)

O21 : (4,5)

O22 : (5,3)

O31 : (7,8)

O32 : (6,2)

O33 : (4,6)

O41 : (6,3)

O42 : (4,4)

Table 5.1.2 specifies the alternate resource requirements of the various operations. The letter letter "Y" indicates that the resource can be used for processing the operation.

5.1.1 RESULTS :

The schedules generated using the four heuristics stated in Section 3.5 are presented in the form of Gantt charts depicted in Figure 5.1 to 5.4. Figures 5.5 to 5.8 show the utilization of various resources corresponding to the heuristics 1 through 4, respectively. Flow times of various jobs for different heuristics are shown in Figures 5.9 to 5.12. The average values of makespan, waiting times, flow times and percentage utilizations of machines, pallets, fixtures and material handling equipments, obtained for the four heuristics are shown in Table 5.1.3.

TABLE 5.1.2 : Alternate Resource Requirements for Various Operations

RESOURCE TYPE	Pallets			Fixtures			Material handling equipents		Tooling requriments
OPERATIONS	P1	P2	P3	F1	F2	F3	Mh1	Mh2	
O11	Y	Y	-	Y	Y	-	Y	Y	T1 & T2
O12	-	-	Y	-	Y	-	-	Y	T3 & T4
O13	-	Y	-	-	-	Y	-	Y	T5
O21	-	Y	-	-	-	Y	Y	-	T2
O22	-	Y	-	-	Y	-	Y	-	T1
O31	Y	-	Y	-	Y	-	Y	Y	T4 & T1
O32	Y	Y	-	Y	-	-	-	Y	T4 & T3
O33	-	Y	Y	-	Y	-	Y	-	T2 & T1
O41	Y	-	Y	Y	-	-	-	Y	T4 & T3
O42	-	-	Y	-	Y	-	Y	Y	T2 & T1

TABLE 5.1.3 : Summary of the Results For Example 1

RULE	TIME IN MINUTES			PERCENTAGE UTILAZATION			
	MAKE SPAN	AVG. FLOW	AVG. WAIT	Mc	Pl	Fx	MHE
MWKR	180	137.50	63.50	39.3	52.3	38.7	17.0
SPT	179	131.75	57.75	39.7	54.0	39.3	17.0
MOPR	183	141.25	67.25	38.7	52.0	38.3	16.5
NEW	175	136.75	62.75	40.0	55.7	40.0	17.5

NOTATIONS:

Mc : Machines, Pl : Pallets, Fx : Fixtures,

MHE : Material Handling Equipment,

SPT : Shortest Processing time,

MWKR : Most Work Remaining,

MOPR : Maximum Operations Remaining,

NEW : Proposed Rule

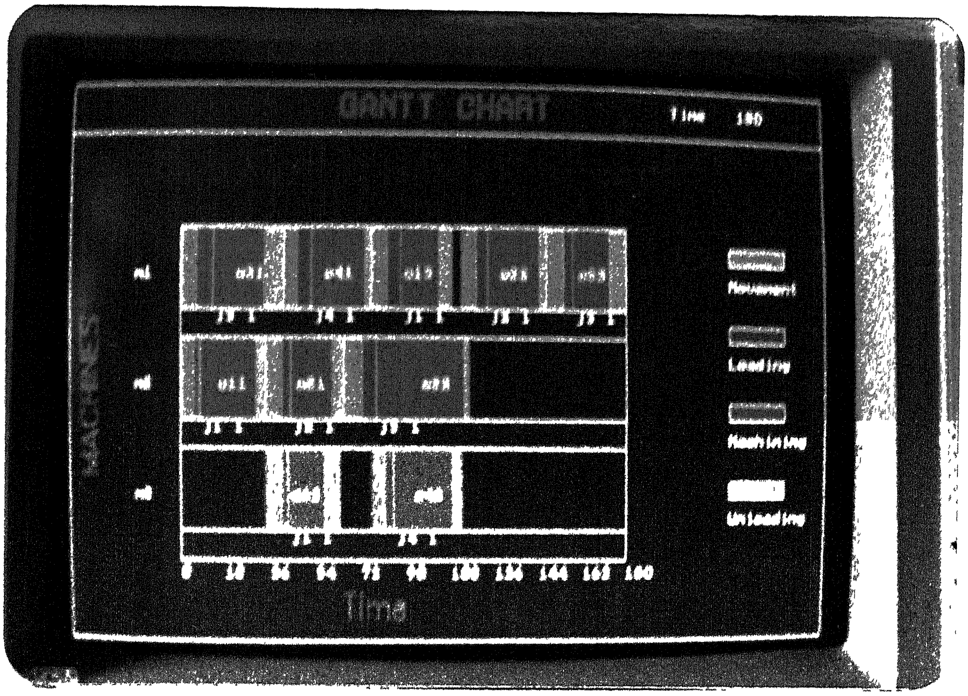


Fig 5.1 Gantt Chart for MWKR

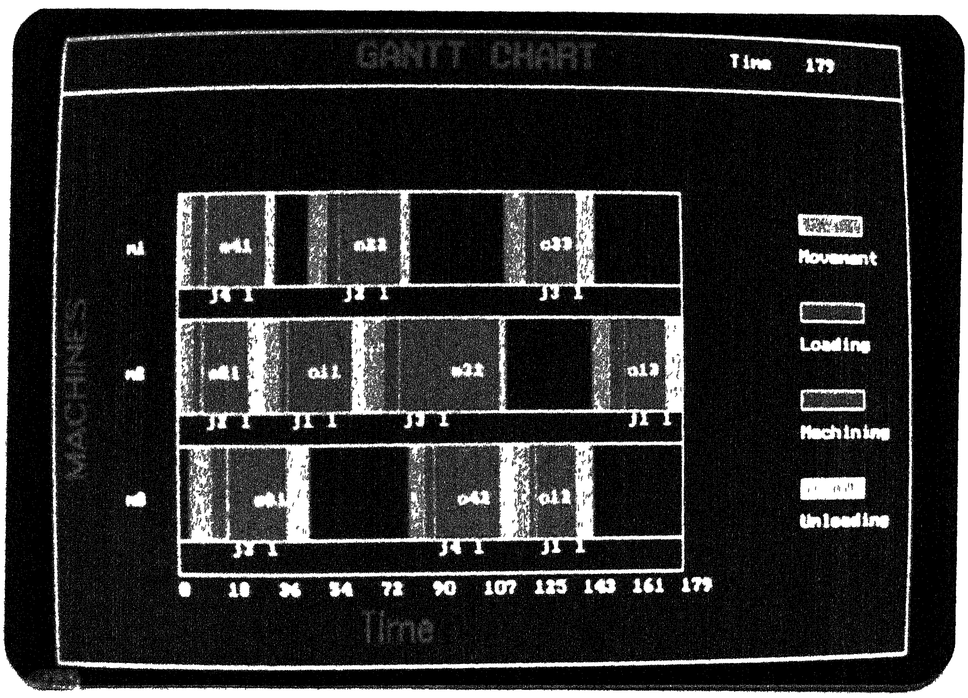


Fig 5.2 Gantt Chart for SPT

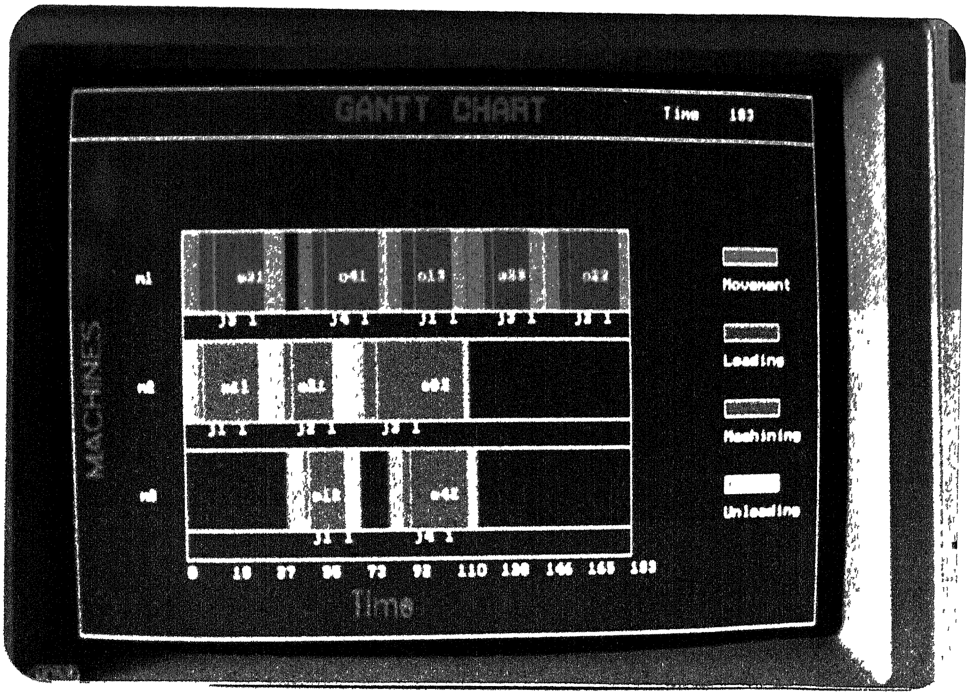


Fig 5.3 Gantt Chart for MOPR

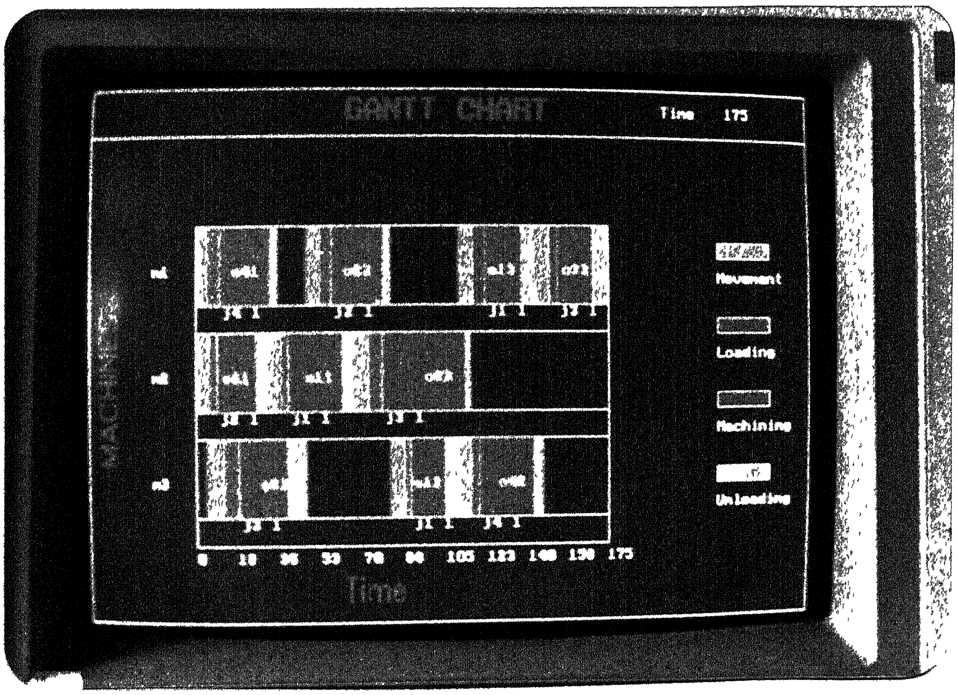


Fig 5.4 Gantt Chart for The Proposed Heuristic

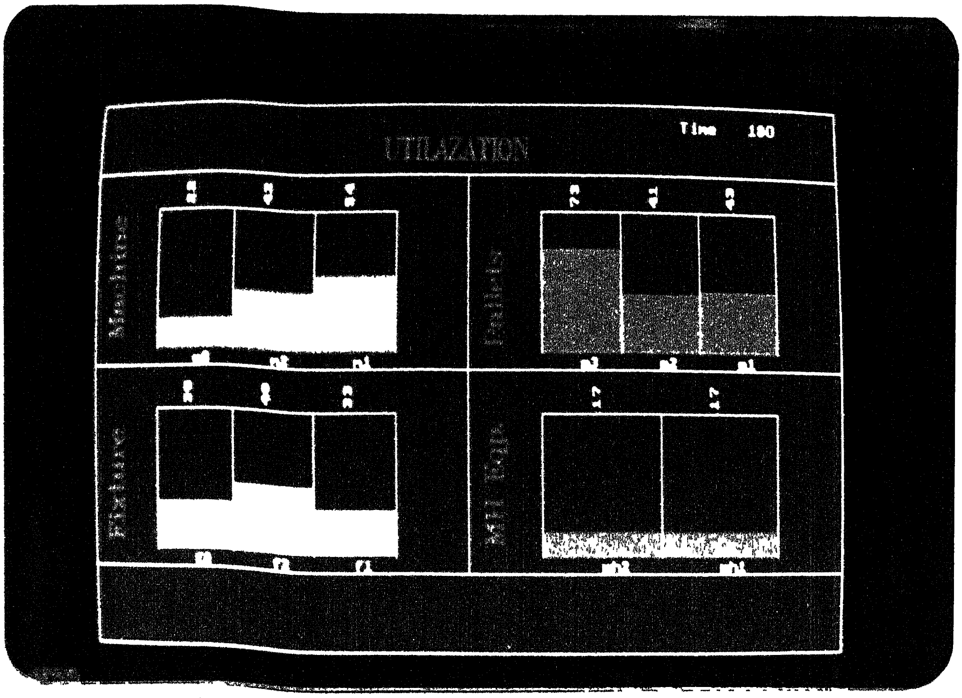


Fig 5.5 Resource Utilization for MWKR

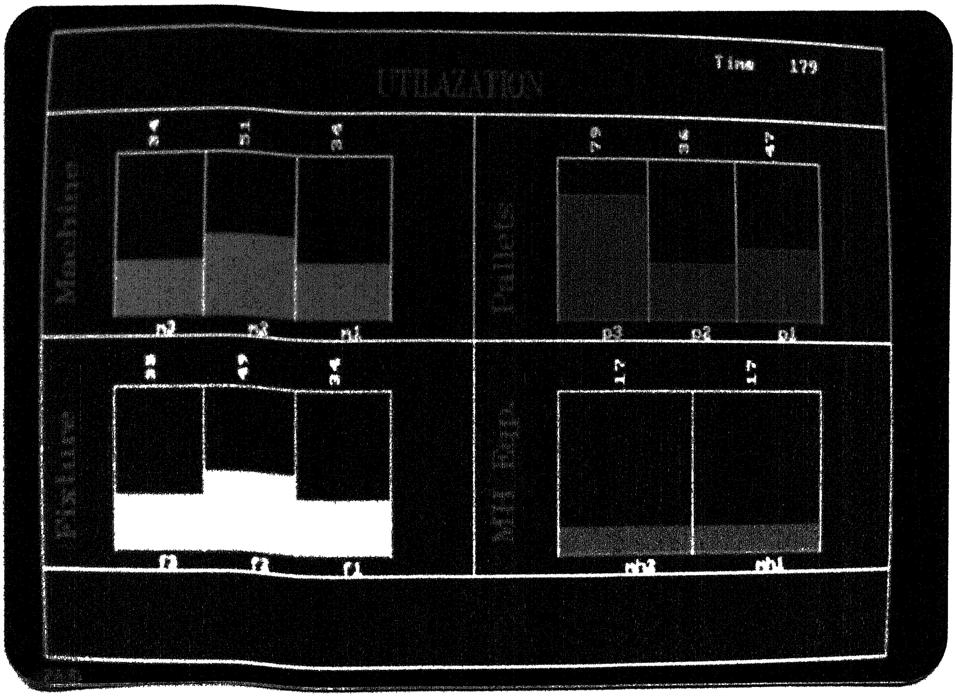


Fig 5.6 Resource Utilization for SPT

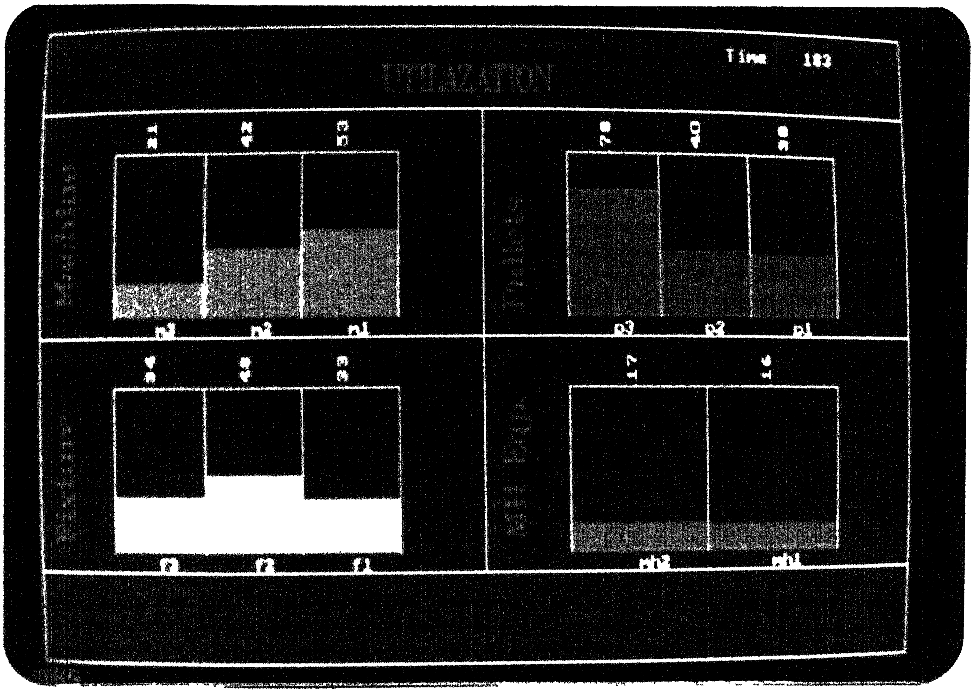


Fig 5.7 Resource Utilization for MOPR

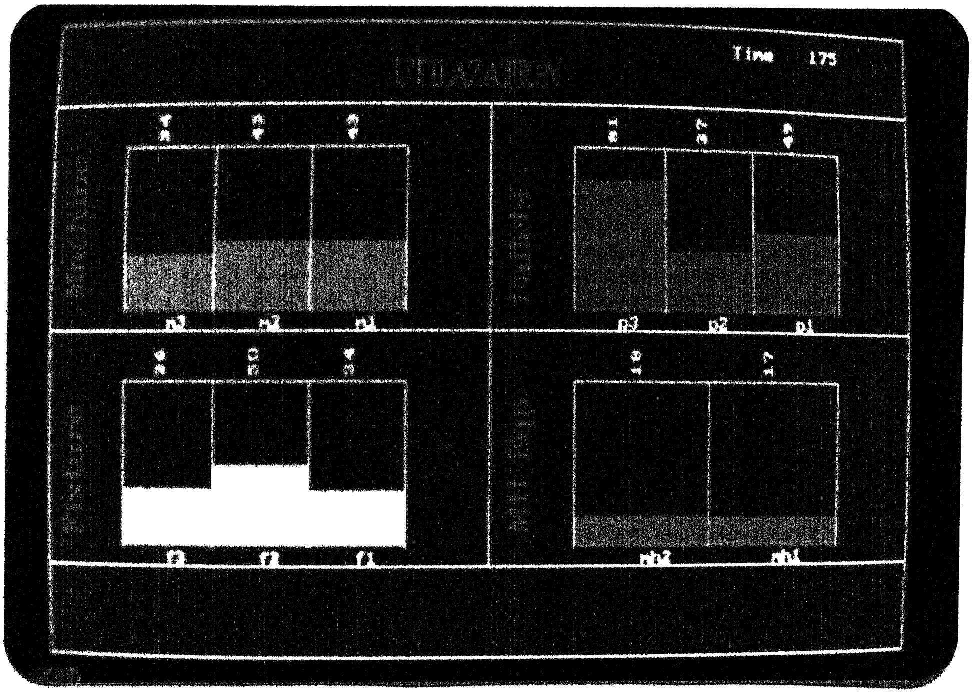


Fig 5.8 Resource Utilization for The Proposed Heuristic

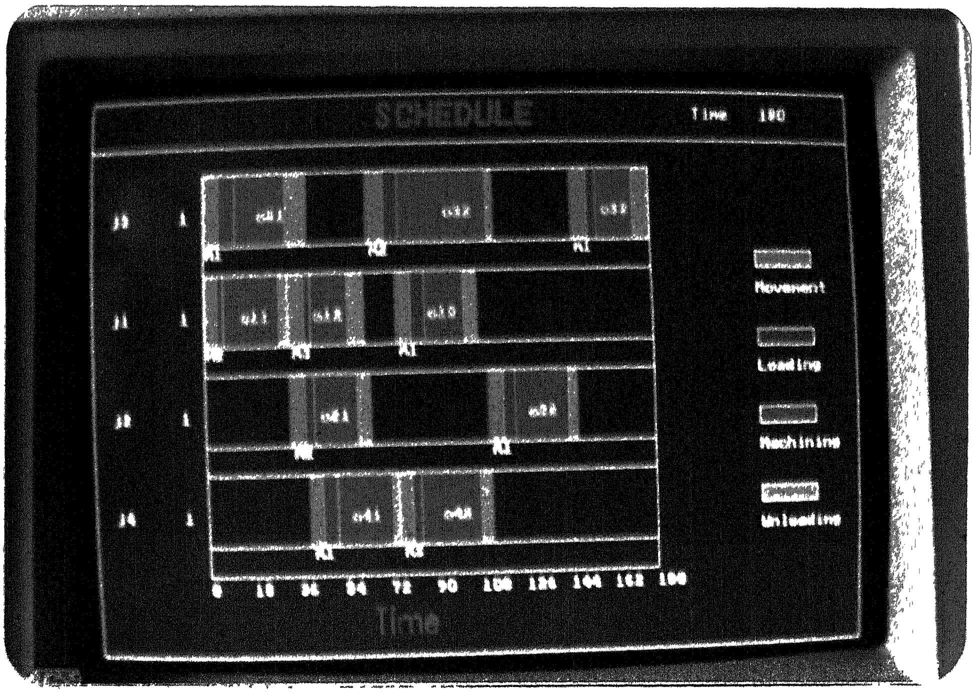


Fig 5.9 Flow Time of Jobs for MWKR

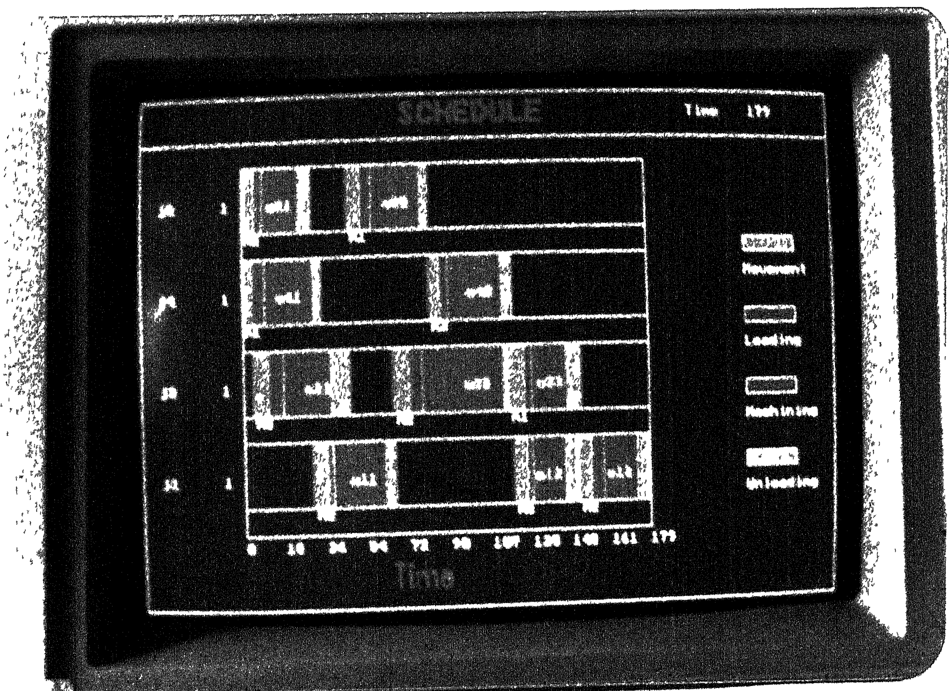


Fig 5.10 Flow Time of Jobs for SPT

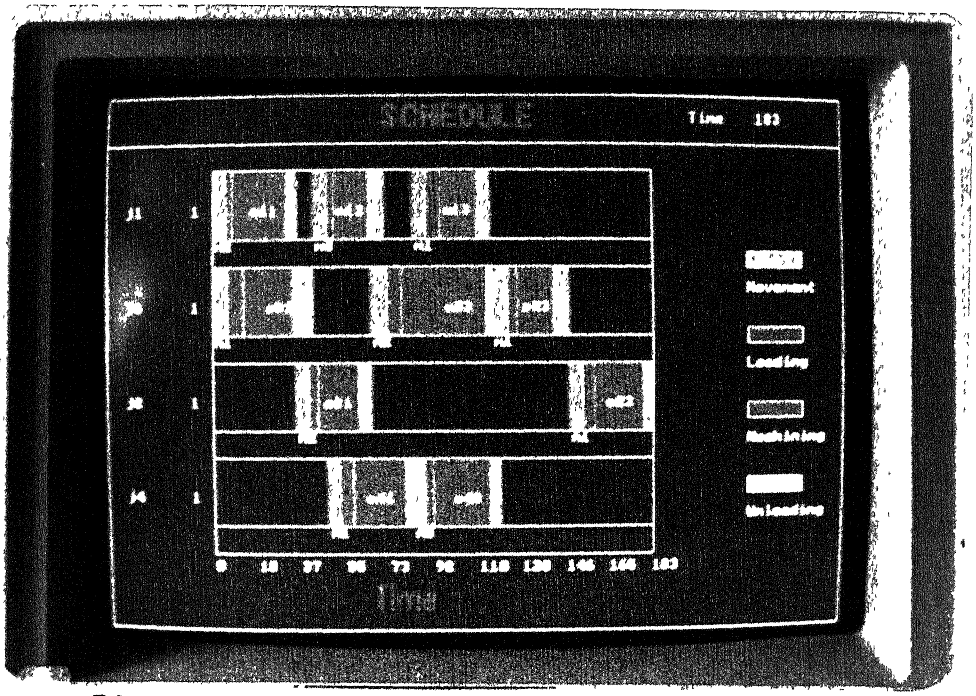


Fig 5.11 Flow Time of Jobs for MOPR

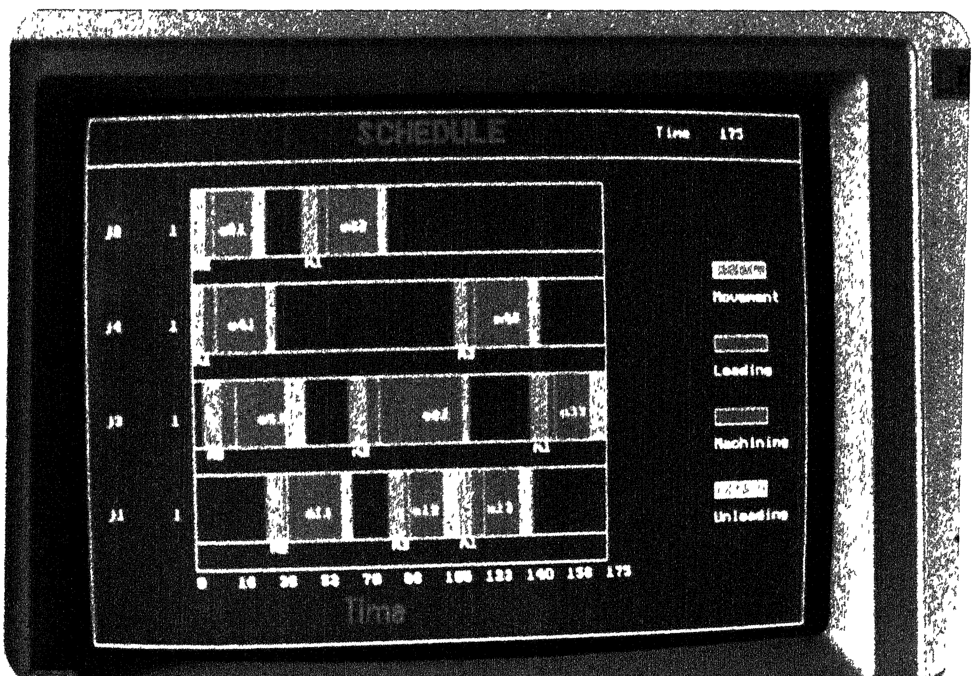


Fig 5.12 Flow Time of Jobs for The Proposed Heuristic

5.1.1.1 Performance Comparison of the Four Heuristics :

The schedules obtained by the four heuristics for Example 1 show that the proposed heuristic outperforms all other heuristics in minimizing the makespan (175 minutes). It is followed by SPT (179 minutes), MWKR (180 minutes) and MOPR (183 minutes) respectively. However, it is worth noting that the difference in the makespan for schedules generated by four heuristics is not significant. The difference between the makespans of the best and the worst schedules being 8 minutes or in other words 4.5% more in the worst case.

For the example under consideration SPT gives best results with respect to minimizing average flow time (131.75 minutes) and average waiting time (57.75 minutes). An examination of the flow times of individual jobs indicates that in case of SPT some jobs are completed in a very short period whereas the others take very long for completion. However, the net result has been a lower average value for these performance measures. The standard deviation of the two measures (flow time and waiting time) from the mean for SPT are 41.47 minutes and 31.2 minutes respectively. The proposed rule with average flow time of 136.75 minutes and average waiting time of 62.75 minutes stands second in performance (standard deviations being 39.1 minutes and 24.75 minutes respectively). The performance of MWKR with average flow time of 137.50 minutes and average wait time of 63.5 minutes (deviations 33.33 and 27.6 respectively) and MOPR with average flow time of 141.25 minutes and average wait time of 67.25 minutes (deviations 31.48 and 24.75 respectively) can be rated

third and fourth respectively.

The percentage utilization of resources is the best for the proposed heuristic. Its better performance with respect to utilization measure is because of two reasons (i) lower makespan, and (ii) smaller idle time on machines. For the proposed heuristic average percentage utilization of various resources is more than the percentage utilization obtained by any other heuristic. In addition to a higher utilization percentage, it also results in a uniform loading of the three machines considered in the example. The performance of SPT for the problem under consideration can be rated as the second best with respect to utilization measure. A large deviation (31.2) in the waiting times of the jobs and a higher makespan has resulted in a low percentage utilization for this rule. The utilization performance measure of resources for MWKR and MOPR ranks third and fourth respectively.

5.2 EXAMPLE 2

This example is an illustration for scheduling problem with non-linear precedence constraints between operations of a job and batch size equals to one. Let us consider following shop floor environment :

i) Three machines : M1(4), M2(4) and M(3).
Number inside the bracket indicates the machine tool magazine capacity.

ii) Three pallets : P1(2), P2(2) and P3(2).
Number inside the bracket indicates the number of pallets in the system.

iii) Three fixture : F1(2), F2(2) and F3(1).

Number inside the bracket indicates the number of fixtures in the system.

iv) Two material handling equipments : MH1(2) and MH2(1).

Number inside the bracket indicates the number of material handling equipments in the system.

v) Five type of tools : Same as in Example 1.

Now, suppose that three different jobs each with a batch size of one are to be scheduled for the various operations. We refer to these jobs as J1, J2 and J3. Further, the operations that are to be performed on each job and the order in which they must be performed are as follows :

J1 : O11 (1), O12 (1) and O13 (2).

J2 : O21 (1) and O22 (1).

J3 : O31 (1) and O32 (2).

The number inside the bracket indicates the precedence of operations.

Table 5.2.1 specifies the operation times for various operations on different machines. In the Table, a blank against a machine indicates the operation cannot be performed by the particular machine and "*" denotes the preferred machine on account of technological requirements such as surface finish, etc. among alternate machines

The secondary material handling time (in minutes) required for each job is as follows :

J1 : 5

TABLE 5.2.1 : Operation Times on Various Machines

MACHINES	M1	M2	M3
OPERATIONS	(Machining Time in Minutes)		
011	-	-	19
012	-	31	-
013	20*	-	21
021	-	31*	33
022	18	-	-
031	33*	35	-
032	-	-	30
033	19	-	-

TABLE 5.2.2 : Alternate Resource Requirements for Various Operations

RESOURCE TYPE	Pallets			Fixtures			Material handling equipents		Tooling requriments
OPERATIONS	P1	P2	P3	F1	F2	F3	Mh1	Mh2	
O11	-	-	Y	-	-	Y	-	Y	T2 & T1
O12	Y	-	-	Y	-	-	Y	-	T1 & T4
O13	-	-	Y	-	Y	-	-	Y	T1
O21	Y	-	-	-	-	Y	-	Y	T3
O22	-	Y	-	Y	-	-	Y	Y	T1
O31	Y	Y	Y	-	Y	-	Y	Y	T4 & T1
O32	Y	Y	Y	Y	Y	-	Y	Y	T5 & T3

TABLE 5.2.3 Summary of Results for Example 2.

RULE	TIME IN MINUTES			PERCENTAGE UTILAZATION			
	MAKE SPAN	AVG. FLOW	AVG. WAIT	Mc	Pl	Fx	MHE
MWKR	142	124.00	47.70	40.0	32.0	41.3	11.0
SPT	187	116.70	40.30	30.7	24.7	32.7	08.5
MOPR	121	106.70	30.30	47.3	37.7	48.3	13.0
NEW	121	106.70	30.30	47.3	37.7	48.3	13.0

Notations :

Mc : Machines, Pl : Pallets, Fx : Fixtures,

MHE : Material Handling Equipment,

SPT : Shortest Processing time,

MWKR : Most Work Remaining,

MOPR : Maximum Operations Remaining,

NEW : Proposed Rule

TABLE 5.2.4 Standard Deviations on Flow Time and Waiting Time

RULE	STANDARD DEVIATION IN MINUTES	
	FLOW TIME	WAIT TIME
MWKR	16.37	29.5
SPT	61.07	47.35
MOPR	23.96	17.04
NEW	23.96	17.04

J2 : 5

J3 : 6

The loading and unloading times (in minutes) for various operations are given below :

Operation : (Loading, Unloading)

O11 : (4,6)

O12 : (5,5)

O13 : (4,3)

O21 : (6,4)

O22 : (6,5)

O31 : (5,3)

O32 : (4,5)

Table 5.2.2 specifies the alternate resource requirements of the various operations. The letter "Y" indicates that the resource can be used for processing the operation.

5.2.1 RESULTS :

The average values of makespan, waiting times, flow times and percentage utilizations of machines, pallets, fixtures and material handling equipments, obtained for the four heuristics are shown in Table 5.2.3.

5.2.1.1 Performance Comparison of the Four Heuristics :

The schedules obtained by the four heuristics for Example 2 show that the proposed heuristic and MOPR (maximum operations remaining) give identical results. Moreover, their performance for Problem 2 is superior than the other two heuristics for all

the performance measures under consideration. The makespan values for both MOPR and the proposed heuristic are 121 minutes. SPT gives the worst results with a makespan of 187 minutes. The corresponding value for MWKR being 142 minutes. Unlike Example 1, it is observed that there is a considerable difference between the makespans obtained by the best (MOPR and proposed heuristic) and the worst heuristic. It may be noted that the makespan for SPT is 50% more than the makespan of the best heuristics.

Performances of the four heuristics with regard to average flow time and average wait time is somewhat different when compared with the makespan time. In table 5.2.3, we observe that MOPR and the proposed rule result in best performance with average flow time of 106.7 minutes and average wait time 30.3 minutes for both the heuristics. However, the positions occupied by the remaining two heuristics (when compared considering makespan time) have got interchanged.

The reason for the better performance of SPT as compared to MWKR can be mainly attributed to large deviation in the flow time and waiting time of jobs.

The standard deviations on flow time and waiting time for the four heuristics are given in Table 5.2.4.

With regard to the percentage utilization of resources is concerned the two heuristics (MOPR and the proposed heuristic) with makespan time equal to 121 minutes give the best performance. The performance of SPT is the poorest in terms of percentage utilization. The reasons for its poor performance are

: (i) larger makespan and (ii) a large deviation in waiting time (47.35 minutes) which in effect shows an excessive idle time on the resources in the system.

5.3 EXAMPLE 3

This example is an illustration for scheduling problem with non-linear precedence constraints between operations of a job and batch size greater than one. Let us consider the shop floor environment to be same as in Example 2.

Now, let us suppose that two different jobs each with a batch size of two to be scheduled for operations. We refer to these jobs as J1 and J2. Further, the operations to be performed on each job and the order in which they must be performed are as follows :

J1 : O11 (1), O12 (1) and O13 (2).
J2 : O21 (1) and O22 (1).

The number inside the bracket indicates the precedence of operations.

Table 5.3.1 specifies the operation times for various operations on different machines. In the table, a blank against a machine indicates the operation cannot be performed by the particular machine and "x" denotes the preferred machine on account of technological requirements such as surface finish, etc. among alternate machines.

The secondary material handling time (in minutes) required for each job is as follows :

TABLE 5.3.1 : Operation Times on Various Machines

MACHINES	M1	M2	M3
OPERATIONS	(Machining Time in Minutes)		
O11	34*	35	-
O12	-	-	37
O13	37	-	-
O21	40*	-	37
O22	-	42	-

"*" denotes the preferred machine on account of technological requirements such as surface finish , etc. among alternate machines.

TABLE 5.3.2 : Alternate Resource Requirements for Various Operations

RESOURCE TYPE	Pallets			Fixtures			Material handling equipents		Tooling requriments
OPERATIONS	P1	P2	P3	F1	F2	F3	Mh1	Mh2	
011	-	Y	Y	-	-	Y	-	Y	T3 & T2
012	Y	Y	-	Y	Y	-	Y	Y	T4 & T5
013	Y	-	Y	-	Y	Y	Y	-	T1 & T2
021	Y	-	-	-	-	Y	Y	Y	T3 & T1
022	-	Y	-	Y	-	-	Y	-	T1 & T2

TABLE 5.3.3 Summary of Results for Example 3

RULE	TIME IN MINUTES			PERCENTAGE UTILAZATION			
	MAKE SPAN	AVG. FLOW	AVG. WAIT	Mc	Pl	Fx	MHE
MWKR	306	227.75	114.75	39.0	28.0	39.0	07.0
SPT	258	182.00	069.00	46.3	33.0	46.0	08.0
MOPR	306	227.75	114.75	39.0	28.0	39.0	07.0
NEW	258	182.00	069.00	46.3	33.0	46.0	08.0

Notations :

Mc : Machines, Pl : Pallets, Fx : Fixtures,

MHE : Material Handling Equipment,

SPT : Shortest Processing time,

MWKR : Most Work Remaining,

MOPR : Maximum Operations Remaining,

NEW : Proposed Rule

J1 : 5

J2 : 5

The loading and unloading times (in minutes) for various operations are give below :

Operation : (Loading, Unloading)

O11 : (6,4)

O12 : (4,4)

O13 : (6,5)

O21 : (7,4)

O22 : (6,5)

Table 5.3.2 specifies the alternate resource requirements of the various operations. The letter "Y" indicates that the resource can be used for processing the operation.

5.3.1 RESULTS :

The average values of makespan, waiting times, flow times and percentage utilizations of machines, pallets, fixtures and material handling equipments, obtained for the four heuristics are shown in Table 5.3.3.

5.3.1.1 Performance Comparison of the Four Heuristics :

The schedules obtained by the four heuristics for Example 3 show that the performances of SPT and the proposed heuristic are similar considering all the performance measures. On the other hand, the results for MWKR and MOPR are found to be identical. Therefore, for the sake of subsequent discussions the heuristics, SPT and proposed, are referred as Set 1 while the

remaining two, MOPR and MWKR, are referred as Set 2.

The makespan time (258 minutes) for Set 1 is better than the makespan value (306 minutes minutes) of Set 2 (306 minutes) by 19%. Further, the average waiting time and average flow time are better for Set 1. The flow time and waiting time standard deviations for Set 1 are 64.08 and 47.17 respectively. On the other hand, these values for Set 2 are 67.5 and 50.75 respectively.

The average utilization of resources for Set 1 is higher than the resource utilization for the schedules generated by the heuristics of Set 2. Again, the reason for this behavior can be attributed to larger makespan with more idle time on resources for the heuristics in Set 2. Set 1 heuristics also give a more uniform utilization of the various resources. For example, the deviation on machine utilizations for Set 1 and Set 2 are 21.1 and 26, respectively.

5.4 DISCUSSION :

The results of the different problems evaluated using the developed system highlights the following issues in a generalized scheduling environment :

1) It is difficult to conclude that a given heuristic will give good results for all the problems under generalized scheduling conditions. In generalized scheduling the schedules are equally dependent on other system parameters like pallets, fixtures and material handling equipments. A change in these parametric values may itself change the schedule. Therefore, in addition to

a good heuristic it is highly desirable to give equal importance to the system design.

2) The utilization of material handling equipments is quite low. This implies that there is a good scope of improving the FMS design for the problems under consideration. More machines in the system served by these material handling equipments may improve the utilization of material handling devices. However, a random addition of machines may result into other production planning problems. Therefore, it is desirable to evaluate the performance of any scheduling system on a real life data.

3) The launching of parts with identical resource requirements (Example 3) significantly reduces the effectiveness of FMS in terms of resource utilization and flow times. It is desirable to design a specialized FMS for processing of identical parts.

4) The effectiveness of an FMS, in terms of resource utilization, waiting time and flow times of job, reduces if there are only a few jobs in the system which can use alternate resources. In absence of an alternate resource a job may have to wait for these resources even if a machine is available for processing. This will result in longer makespan and high waiting time as depicted in Example 2.

CHAPTER VI

CONCLUSIONS

An expert system for generalized scheduling and tool management in FMS has been designed and implemented. The expert system has been implemented as a menu driven system. The user is required to provide information about the jobs to be scheduled, precedence constraints, resource constraints, batch sizes, operation times, dispatching heuristic to be used etc. At the end of the session, the system not only provides an actual schedule for the jobs but an analysis of the schedule as well -- it includes statistics about resource utilization, flow times etc.

The present system contains four scheduling heuristics in its static database. These are (i) SPT (ii) MOPR (iii) MWKR and one proposed by us. The scheduling system allows the updating of the knowledge base without affecting the control component. From a purely scheduling point of view the system has the abilities to detect resource conflicts and to determine alternate routes for a given part. In the event of a resource conflict, if an alternate route is found then the plan is amended accordingly.

The performances of the above mentioned heuristics, for generalized scheduling in an FMS, have been compared in Chapter V for three illustrative examples. The limited experience obtained through the three illustrative problems suggests that the proposed weighing scheme has potential to yield better schedules. The performance of the proposed heuristic which

draws upon the suggested weighing scheme has been found to be invariably good for maximizing the resource utilization since it draws upon the information concerning the alternative feasible routes. It may stated that the performance of SPT, in a generalized scheduling environment, is not the same as it is found to be in a job shop condition where the stress is on machines and jobs only. SPT in generalized scheduling, may give very poor results for the make span and average flow time as can be seen in Example 2. The reason for such a poor performance is the delay caused by non availability of other resources for loading a job on a machine. The proposed heuristic tends to give a better performance for the makespan though the average flow time and average waiting time can be slightly higher.

The utilization of resources is found to be more uniform for MOPR, MWKR and the proposed heuristic. On the other hand SPT results in a non-uniform resource utilization with a lot of idle time on a few resources in the system.

The performance of MWKR and MOPR in minimizing the makespan and flow time can at best be rated as average to worse.

Further, with the limited experience obtained from the three illustrative examples, the need for giving due importance to various resources like pallets and fixtures in a generalized scheduling environment has been highlighted. It was scarcity of resources which could be responsible for yielding identical schedules for more than one heuristic in Example 2 and 3.

In Example 3, where two jobs with batch size of 2 each are to be

scheduled, we have found that the makespan time has increased in much greater proportion than expected from the results of example 2. The reason is the launching of parts with identical resource requirements. Hence, for the manufacturing requirement of this kind where identical parts are to be produced a specialized FMS would be desirable.

Although, the importance of having good loading rules can not be neglected in a generalized scheduling environment, yet more stress needs to be given to quality of decisions like short term planning and system planning. This would result in better performance of an FMS in terms of resource utilization.

The developed system can be used as :

i) An analysis tool : The effect of various rules and decisions on a given scheduling problem can be analyzed by suitably changing domain parameters.

ii) An educational tool : New heuristics can be added, without making explicit changes to the program (codes) itself, for examining their viability as loading rule in FMS.

SCOPE FOR FUTURE WORK : The expert system for generalized scheduling and tool management in FMS, developed in this work, is primarily concerned with machining system. However, the same can be extended to include assembly and other shops of an FMS. We have considered only the secondary material handling component of the system whereas in future work the primary material handling component can also be incorporated giving due considerations to various FMS layouts.

Further, a separate process planning module which generates input for the scheduling system can be developed. Such a system must consists of part design, process planning, equipment selection and layout design. This would help reduce any inconsistencies that may arise due to incorrect data input.

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